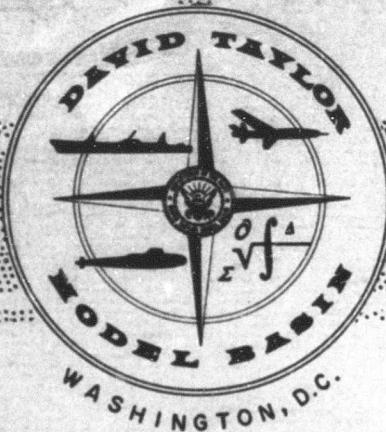


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Report 2201



DEPARTMENT OF THE NAVY

LONGITUDINAL AERODYNAMIC CHARACTERISTICS OF SEVERAL HYPERSONIC AIRCRAFT CONFIGURATIONS AT A MACH NUMBER OF 6.26

HYDROMECHANICS

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AERODYNAMICS

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ACOUSTICS AND
VIBRATION

by

John R. Krouse and Bertram K. Ellis

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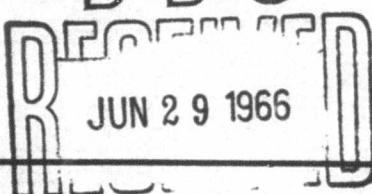
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AERODYNAMICS LABORATORY RESEARCH AND DEVELOPMENT REPORT

D D C



May 1966

Report 2201

**LONGITUDINAL AERODYNAMIC CHARACTERISTICS OF SEVERAL
HYPERSONIC AIRCRAFT CONFIGURATIONS
AT A MACH NUMBER OF 6.26**

by

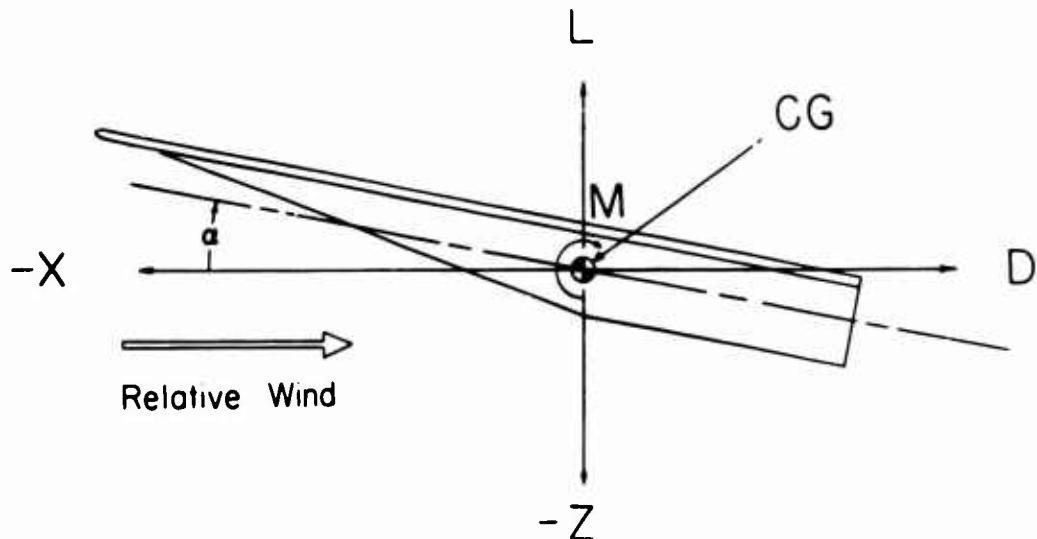
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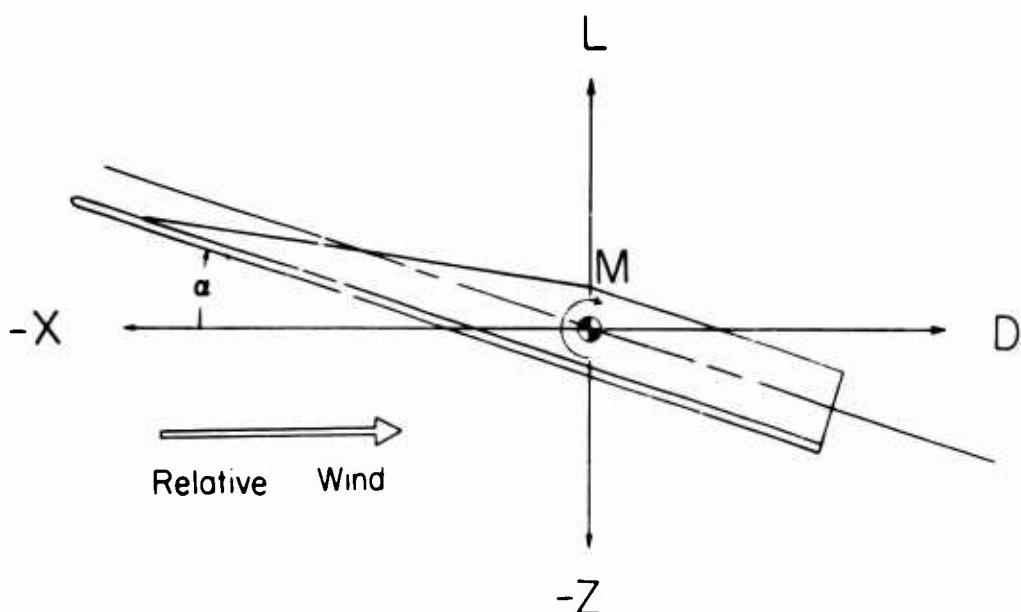
May 1966

**Report 2201
Aero Report 1109**

NOTATION



High Wing



Low Wing

Axis	Force	Force Coefficient	Moment Coefficient
D (X)	D (drag)	$C_D = D/qS$	$C_m = M/qSc$
L (Z)	L (lift)	$C_L = L/qS$	

SYMBOLS

c	wing center-line chord, inches
c.p.	center of pressure (from wing apex), inches
C_D	drag coefficient
C_L	lift coefficient
C_m	pitching moment coefficient
D	drag, lb
L	lift, lb
L/D	lift-to-drag ratio
M	Mach number
p	pressure, psi
q	dynamic pressure, psi
Re	Reynolds number
S	projected wing area, in ²
T	temperature, °R
α	angle of attack, degrees
δ	wing-tip dihedral (positive, toward the fuselage), degrees

Subscripts

b	base of fuselage
t	stagnation conditions
∞	free-stream conditions

Configuration Identification Code

Wings:	W1 - Series 1 Wings (Straight Trailing Edges)
	W2 - Series 2 Wings (Extended Trailing Edges)
Bodies:	B1 - Low-Volume Fuselage
	B2 - High-Volume Fuselage

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SUMMARY

Wind-tunnel tests were conducted at a Mach number of 6.26 to determine the longitudinal aerodynamic characteristics of several conceptual hypersonic aircraft configurations, consisting of various half-cone-cylinder bodies and double-delta wings. Effects of body volume, vehicle orientation, wing planform, and wing-tip dihedral were determined. In general, the lift-to-drag ratios of all high-wing configurations varied slightly over an angle-of-attack range of 0° to 12° , reaching maximum values of roughly 3.2 near 6° . On the other hand, the lift-to-drag ratios of all low-wing configurations increased continuously with increasing angle of attack, eventually reaching maximum values of roughly 3.6 near 10° . In all cases, fuselage base drag accounted for less than 10 percent of the total drag. For the arbitrarily chosen center-of-gravity location, all low-wing configurations were stable but unbalanced; whereas several high-wing configurations were both stable and balanced.

INTRODUCTION

Several recent studies (References 1 through 4) have indicated that hypersonic cruise aircraft will probably require an air-breathing propulsion system utilizing liquid hydrogen fuel in order to obtain adequate range-payload performance characteristics. As a result of the very low density of this fuel (less than one-tenth that of conventional hydrocarbons), hypersonic aircraft will be characterized by very large fuselages necessary to contain an adequate supply of this high-energy propellant. The present investigation was undertaken to determine the longitudinal aerodynamic characteristics of several wing-body configurations, compatible with the aforementioned requirements and the general design philosophy discussed in Reference 5. These configurations were previously tested at a Mach number of 9.45 (Reference 6); the results of tests performed at a Mach number of 6.26 are presented herein. All tests were performed in the Open-Jet Hypersonic Wind Tunnel of the David Taylor Model Basin Aerodynamics Laboratory at a unit Reynolds number of approximately 75,000 per inch.

MODELS AND TEST APPARATUS

The models consisted of two families of double-delta wings with cylindrically blunted leading edges and two half-cone-cylinder fuselages. One family of wings had straight trailing edges, and the other had extended trailing edges; both series of wings had wing-tip dihedral of 0° and 45° and a constant thickness equal to 1.25 percent of the wing centerline chord (Figure 1). Positive and negative dihedral were obtained by mounting the wing so that the wing-tip deflection was toward and away from the fuselage, respectively. Both bodies had the same length but different maximum diameters (Figure 2). The wings and bodies were machined from stainless steel, and were completely interchangeable. A typical complete wing-body configuration is shown in Figure 3.

Force data were obtained with a Task Corporation, six-component, internal strain-gage balance. Data readout was acquired with a Beckman 210 solid-state system, which senses, measures, digitizes, and records the test data on magnetic tape for direct entry into an IBM 7090 computer. Fuselage base pressure was measured with a Pace 0 - 0.3 psid transducer. The data repeatability was as follows:

C_L ± 0.002	L/D ± 0.04
C_D ± 0.001	M ± 0.02
C_m ± 0.0001	c.p. ... ± 0.02 in.

TEST CONDITIONS AND PROCEDURES

All tests were conducted under the following free-stream conditions:

	Average	Maximum	Minimum
p_∞ , psi	0.0506	0.0514	0.0499
T_∞ , $^{\circ}$ R	145.5	147.6	143.7
q_∞ , psi	1.381	1.401	1.361
M	6.26	6.32	6.19
Re, per inch	77,490	80,780	74,690

All possible wing-body combinations were tested by varying the angle of attack of the model between limits of $\pm 12^\circ$ at a constant rate of one degree per second, while simultaneously obtaining continuous data during wind-tunnel operation. Physically, the models were mounted in the wind tunnel with the wing on top of the body. For each run, the data for half the angular range (upward) were interpreted as representing a high-wing model at positive α , the other half (downward) representing a low-wing model also at positive α . Force and moment components were measured, from which the following quantities were computed: C_L , C_D , L/D , C_m , and c.p. Fuselage base pressure was measured behind the cylindrical afterbody, midway between the sting and outer edge of the body.

RESULTS AND DISCUSSION

Lift, drag, and pitching moment coefficients, aerodynamic efficiency, and center of pressure were obtained for all possible wing-body combinations for angles of attack up to 12° . All coefficients are presented as a function of α (Figures 4 through 13), and are referenced to the projected wing area and wing center-line chord. The axis system, force and pitching moment coefficients, and configuration identification code are defined in the notation and symbols. The effects of body volume, vehicle orientation (high-wing or low-wing), wing planform, and wing-tip dihedral are discussed in the following paragraphs. A comparison is made between the experimental results and theoretical calculations of the aerodynamic efficiency for two representative high-wing, flat-plate configurations (B1W1 and B2W2).

AERODYNAMIC EFFICIENCY

For the high-wing configurations, the lift-to-drag ratio was positive at an angle of attack of 0° , reached a maximum value of roughly 3.2 at $\alpha \approx 6^\circ$, and decreased slightly thereafter. For the low-wing configurations, on the other hand, the lift-to-drag ratio was negative at an angle of attack of 0° , but it increased with increasing α , to a maximum value of roughly 3.6 near $\alpha = 10^\circ$ (Figure 6). Values of $(L/D)_{\max}$ at $M = 6.26$ were about 15 percent higher than those obtained for corresponding configurations at $M = 9.45$ (Reference 6).

The lift-to-drag ratios of the configurations with the small (B1) fuselage were higher than those of corresponding configurations with the large (B2) fuselage over most of the angle-of-attack range (Figure 6). Deflecting the wing tips of the high-wing configurations into the relative wind ($\delta = 45^\circ$) increased the aerodynamic efficiency except at the higher angles of attack (Figure 7a). Deflecting the wing tips of the low-wing configurations into the relative wind ($\delta = -45^\circ$, in this case) gave higher L/D ratios than the configurations without dihedral up to $\alpha \approx 5^\circ$; negative dihedral was also superior to positive dihedral up to $\alpha \approx 10^\circ$ (Figure 7b). In general, configurations with Series 2 Wings had slightly better L/D ratios than corresponding configurations with Series 1 Wings (Figure 8). In all cases, the base drag accounted for less than 10 percent of the total drag.

Newtonian impact theory was used to calculate the lift-to-drag ratio of two flat-plate, high-wing configurations; namely, B1W1 and B2W2. The pertinent equations were obtained or derived from Reference 7. Each complete wing-body configuration was considered as three component parts: (1) half-cone forebody, (2) half-cylinder afterbody, and (3) wing. The coefficients were corrected to a common reference area (the exposed wing area) and then added for each component part to obtain the total coefficients of a complete wing-body configuration. Initial computations, neglecting wing thickness, produced fairly poor correlation with the experimental data (Figure 9). Including the drag of the cylindrically blunted wing leading edge gave considerably better agreement. A further attempt was made to improve the results by accounting for skin-friction drag. The following simplifying assumptions were made: (1) the total exposed wing-body area was treated as a flat plate, and (2) the skin-friction was considered independent of α . For a Reynolds number based on the wing center-line chord, the coefficient of friction (C_f) was obtained from Figure 3 of Reference 8 by extrapolation to the existing temperature ratio. This viscous drag coefficient was corrected to the common reference area and added to the Newtonian drag coefficient, producing excellent agreement with the experimental data at $\alpha = 0^\circ$ and $\alpha = 12^\circ$. At intermediate angles of attack, the experimental results

were considerably higher than the theoretical values. On the other hand, at $M = 9.45$, excellent correlation was obtained between theory and experiment over the entire angle-of-attack range.

LONGITUDINAL STATIC STABILITY

The longitudinal static stability characteristics are summarized in Tables 1 and 2. The evaluation of the various configurations, in terms of C_m , was based on a center of gravity located seven inches from the wing apex (63.6 percent of the wing center-line chord). The pitching moment coefficients of all configurations were computed about this c.g. location, even though it will vary slightly with different wing-body combinations. Nevertheless, the arbitrarily chosen c.g. position is believed to be fairly representative of a similarly designed, full-scale aircraft. Moving the center of gravity forward or aft will affect the stability characteristics accordingly, but the relative merits of the various configurations should remain unchanged.

The high-wing configurations with $\delta = -45^\circ$ were unstable and unbalanced (Figure 10c). Of the remaining configurations, those with W2 wings were more stable than the corresponding configurations with W1 wings (Figures 10 and 11). All low-wing configurations were stable but unbalanced; whereas several high-wing configurations with $\delta = 0^\circ$ and $\delta = 45^\circ$ were both stable and balanced (Figure 12). Moreover, a few of these high-wing configurations were balanced at angles of attack corresponding to the maximum lift-to-drag ratio (Figure 7). The center of pressure was practically independent of angle of attack for $4^\circ < \alpha < 12^\circ$ for all high-wing configurations and nearly independent of angle of attack for $8^\circ < \alpha < 12^\circ$ for all low-wing configurations (Figure 13).

Aerodynamics Laboratory
David Taylor Model Basin
Washington, D. C.
April 1966

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Table 1
 Summary of Longitudinal Static Stability Characteristics
 (High-Wing Configurations)

Body	Wing-Tip Dihedral	Stability Characteristics	Remarks
Series 1 Wings (Straight Trailing Edges)			
B1	$\delta = 0^\circ$	Stable and balanced	A
	$\delta = 45^\circ$	Stable and Marginally balanced	NA
	$\delta = -45^\circ$	Unstable and unbalanced	NA
B2	$\delta = 0^\circ$	Stable and unbalanced	NA
	$\delta = 45^\circ$	Stable and balanced	A
	$\delta = -45^\circ$	Unstable and unbalanced	NA
Series 2 Wings (Extended Trailing Edges)			
B1	$\delta = 0^\circ$	Stable and balanced	A
	$\delta = 45^\circ$	Stable and unbalanced	NA
	$\delta = -45^\circ$	Marginally stable and unbalanced	NA
B2	$\delta = 0^\circ$	Stable and balanced	A
	$\delta = 45^\circ$	Stable and marginally balanced	NA
	$\delta = -45^\circ$	Unstable and unbalanced	NA

A - Acceptable

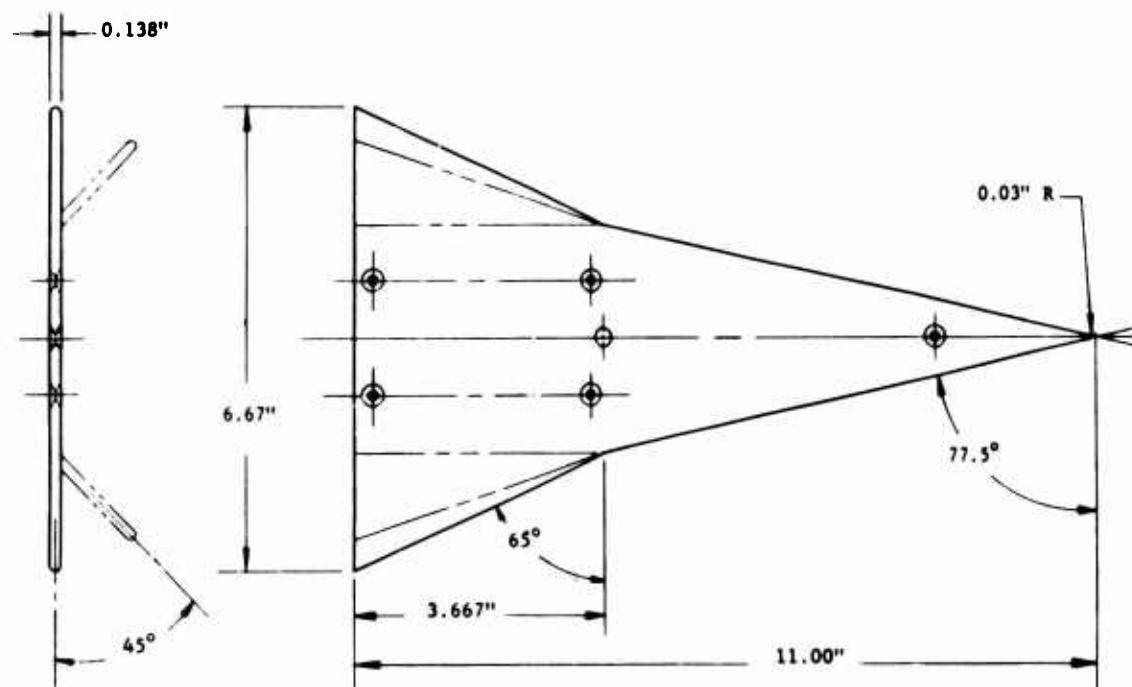
NA - Not Acceptable

Table 2
Summary of Longitudinal Static Stability Characteristics
(Low-Wing Configurations)

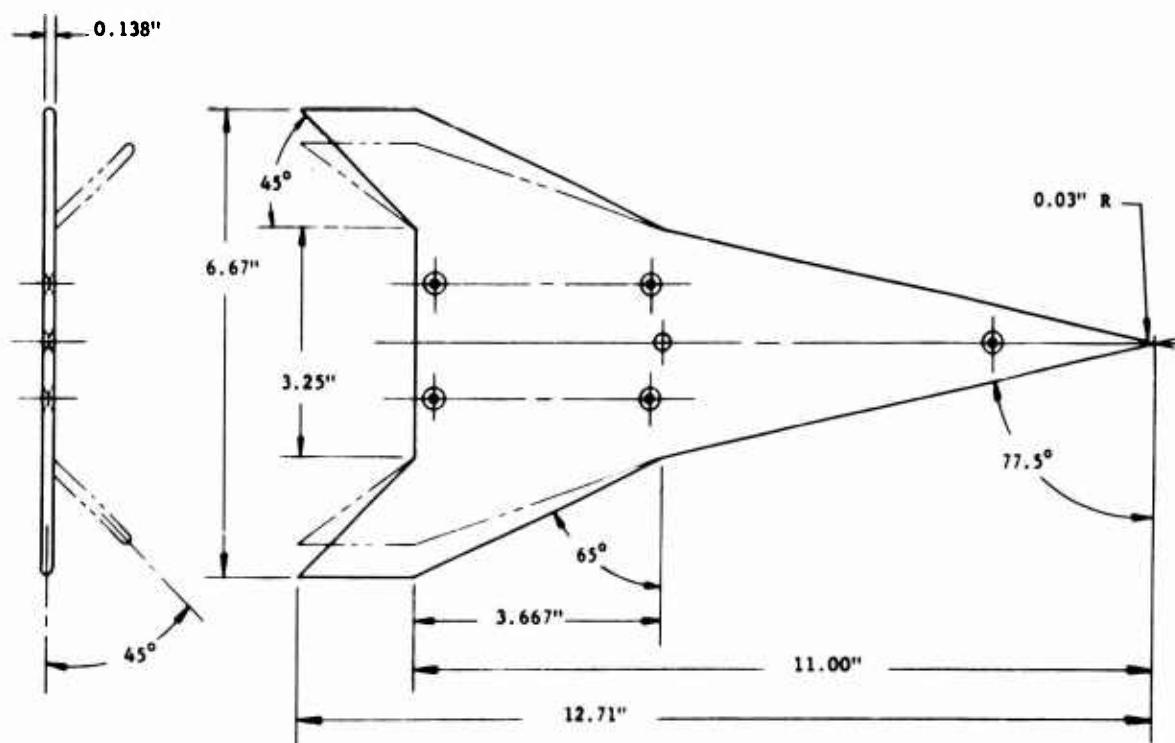
Body	Wing-Tip Dihedral	Stability Characteristics	Remarks
Series 1 Wings (Straight Trailing Edges)			
B1	$\delta = 0^\circ$	Stable and unbalanced	NA
	$\delta = 45^\circ$	Stable and unbalanced	NA
	$\delta = -45^\circ$	Stable and unbalanced	NA
B2	$\delta = 0^\circ$	Stable and unbalanced	NA
	$\delta = 45^\circ$	Stable and unbalanced	NA
	$\delta = -45^\circ$	Stable and unbalanced	NA
Series 2 Wings (Extended Trailing Edges)			
B1	$\delta = 0^\circ$	Stable and unbalanced	NA
	$\delta = 45^\circ$	Stable and marginally balanced	NA
	$\delta = -45^\circ$	Stable and unbalanced	NA
B2	$\delta = 0^\circ$	Stable and unbalanced	NA
	$\delta = 45^\circ$	Stable and unbalanced	NA
	$\delta = -45^\circ$	Stable and unbalanced	NA

A - Acceptable

NA - Not Acceptable

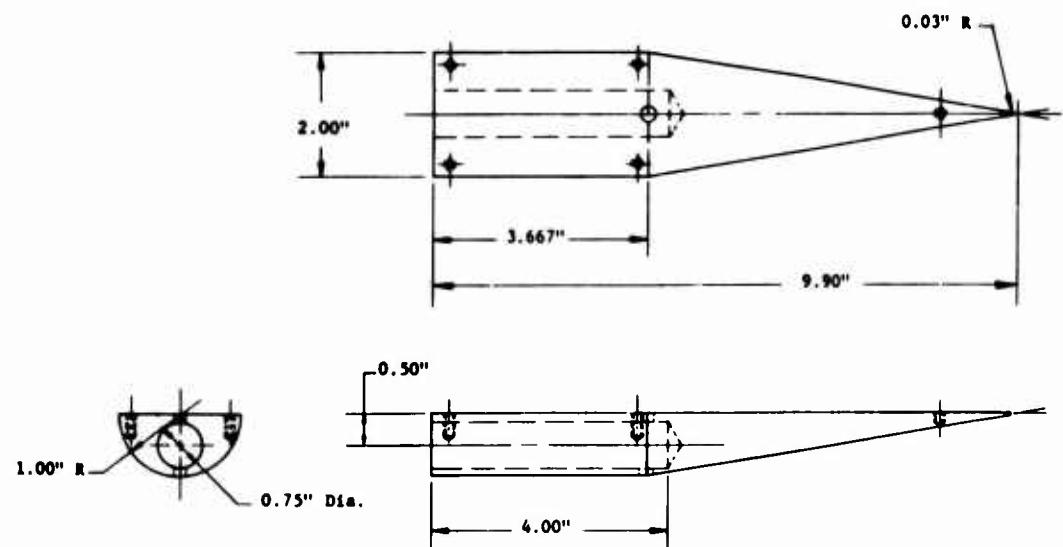


Series 1 Wings (Straight Trailing Edges)

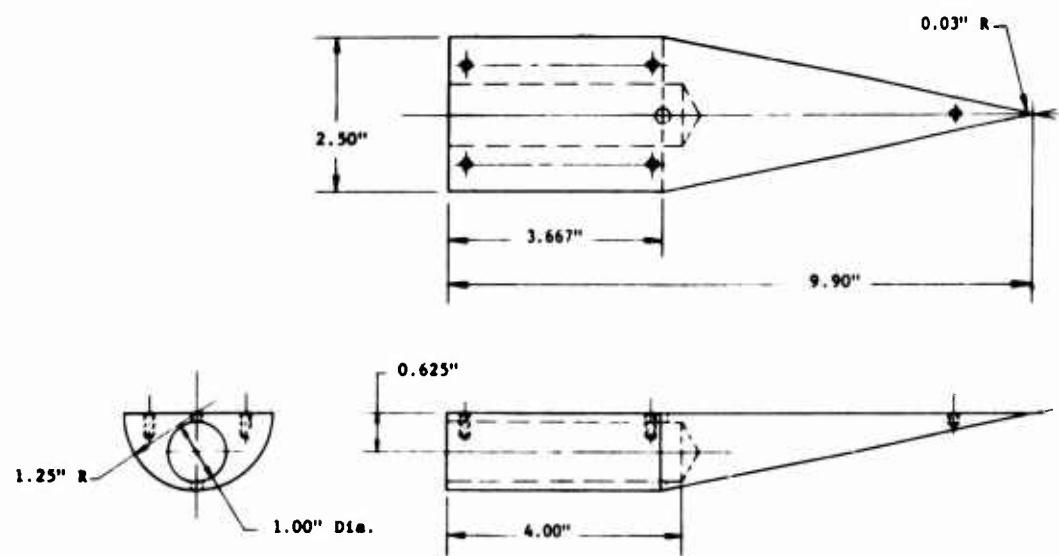


Series 2 Wings (Extended Trailing Edges)

Figure 1 - Principal Dimensions of Wing Configurations

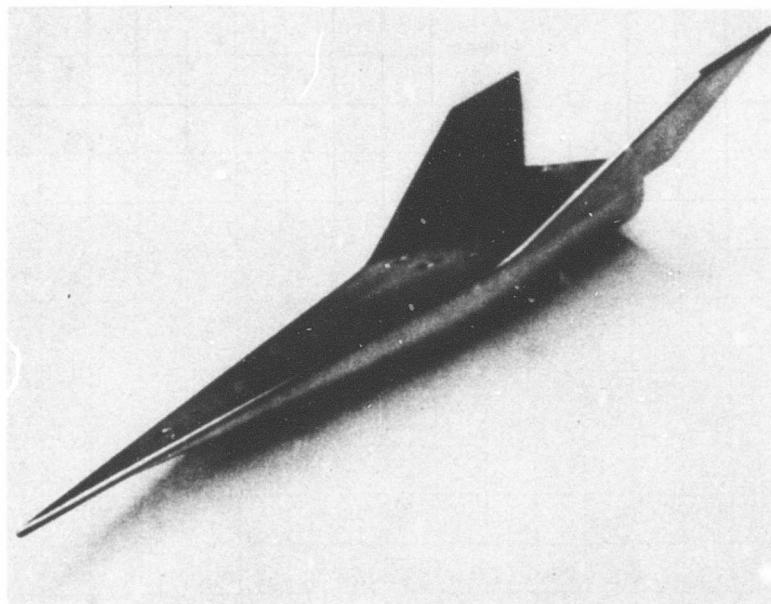


(a) Low-Volume Fuselage

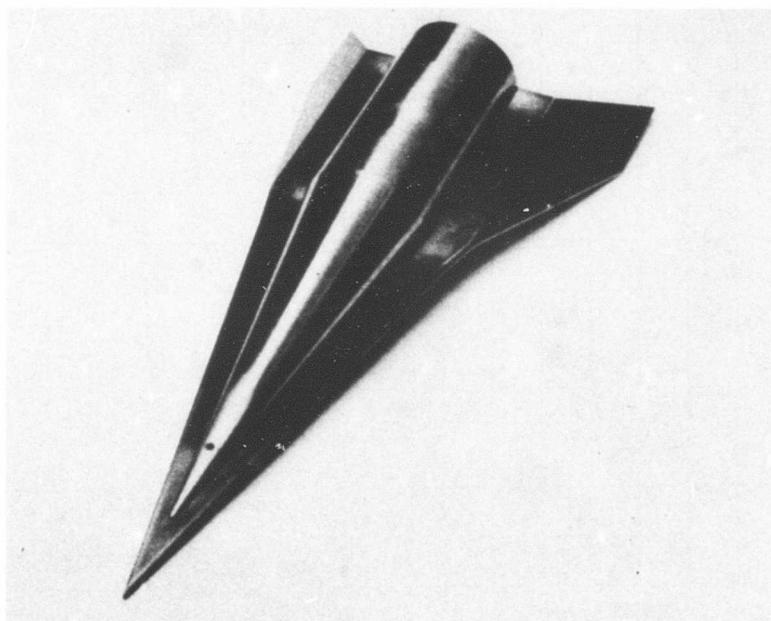


(b) High-Volume Fuselage

Figure 2 - Principal Dimensions of Fuselage Configurations



(a) High-Wing Configuration



(b) Low-Wing Configuration

Figure 3 - Photographs of a Typical Wing-Body Configuration (BlW2 ; $\delta = -45^\circ$)

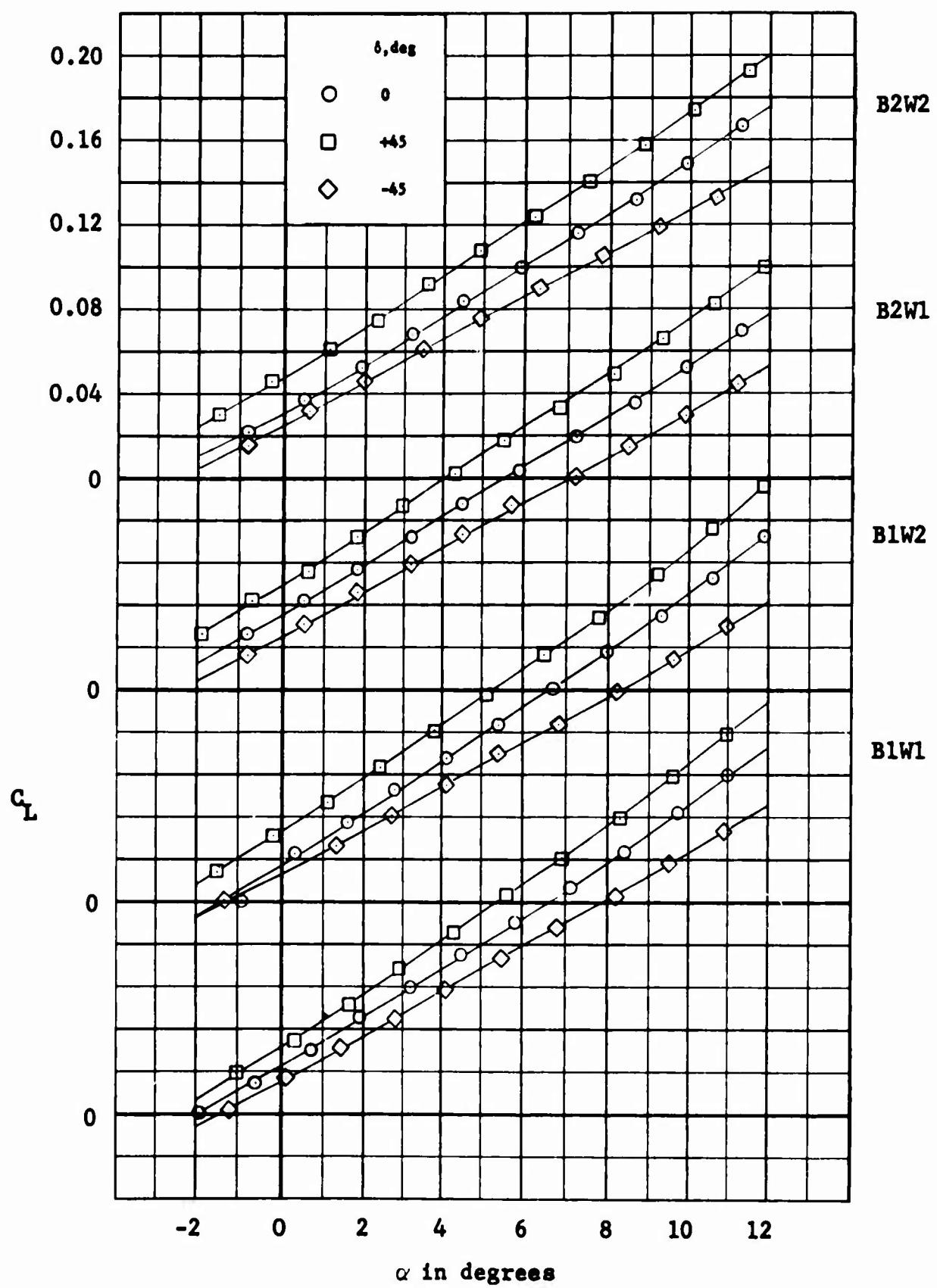


Figure 4 - Variation of Lift Coefficient with Angle of Attack
 (a) High-Wing Configurations

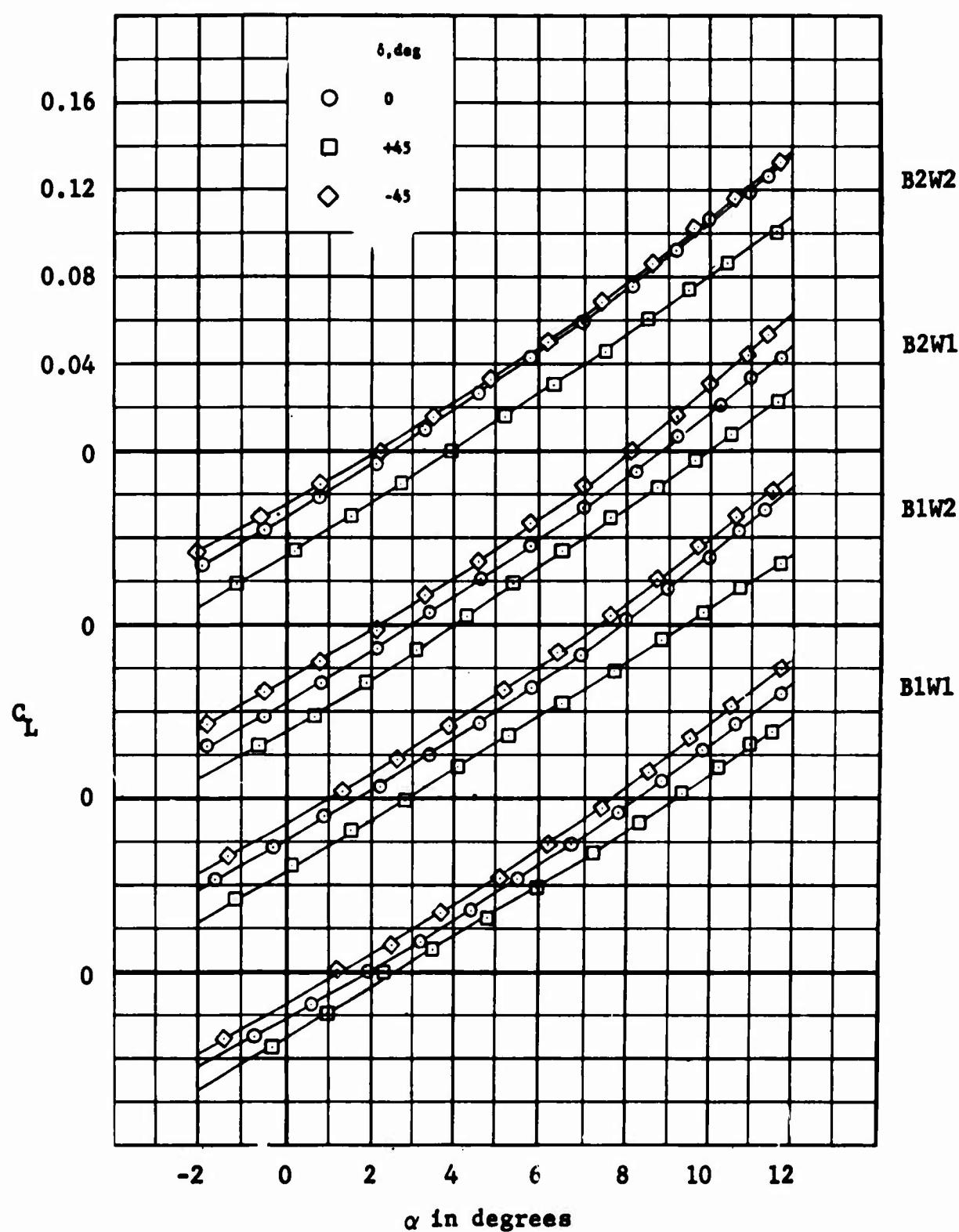


Figure 4 (Concluded)
(b) Low-Wing Configurations

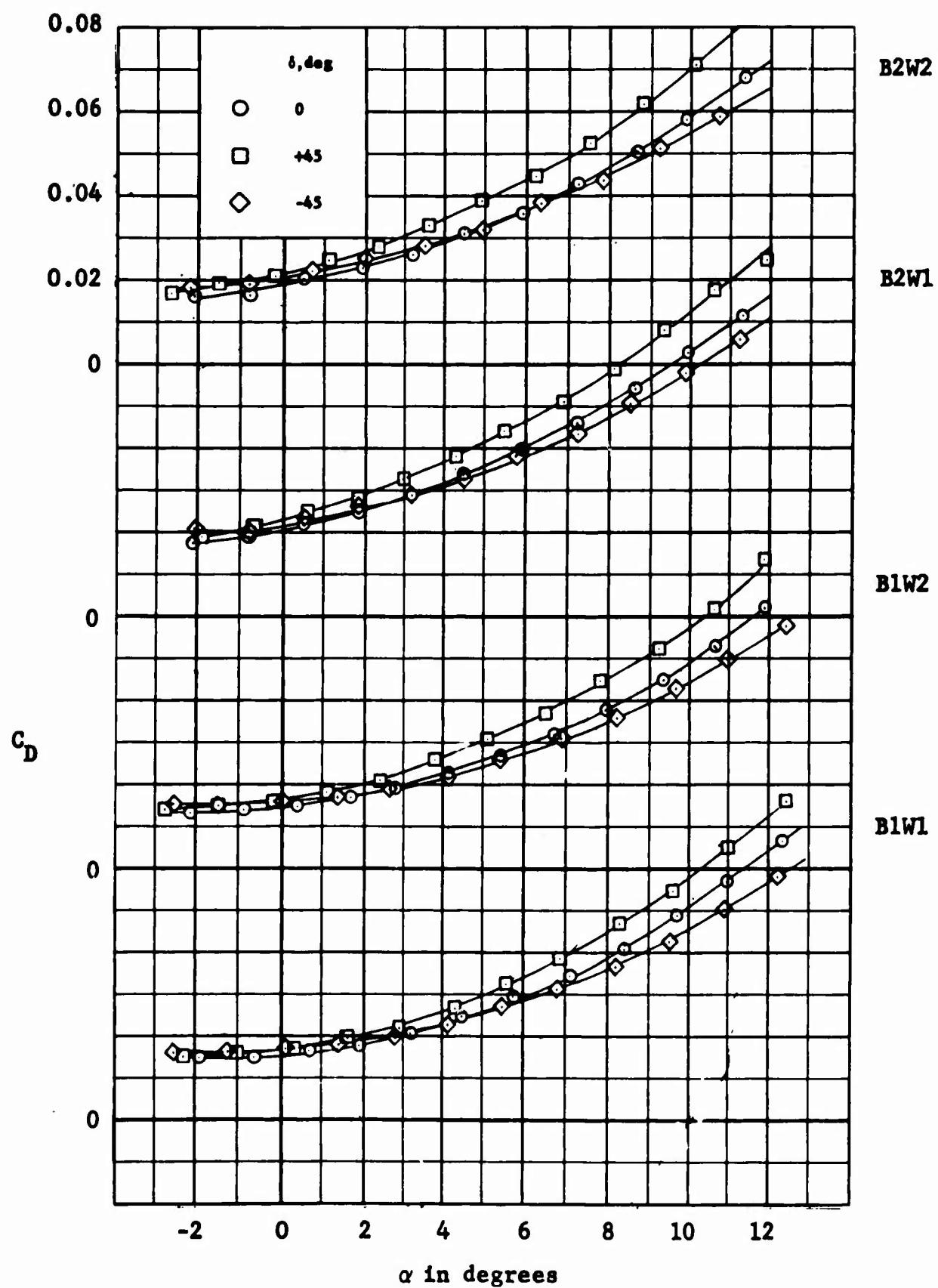


Figure 5 - Variation of Drag Coefficient with Angle of Attack
 (a) High-Wing Configurations

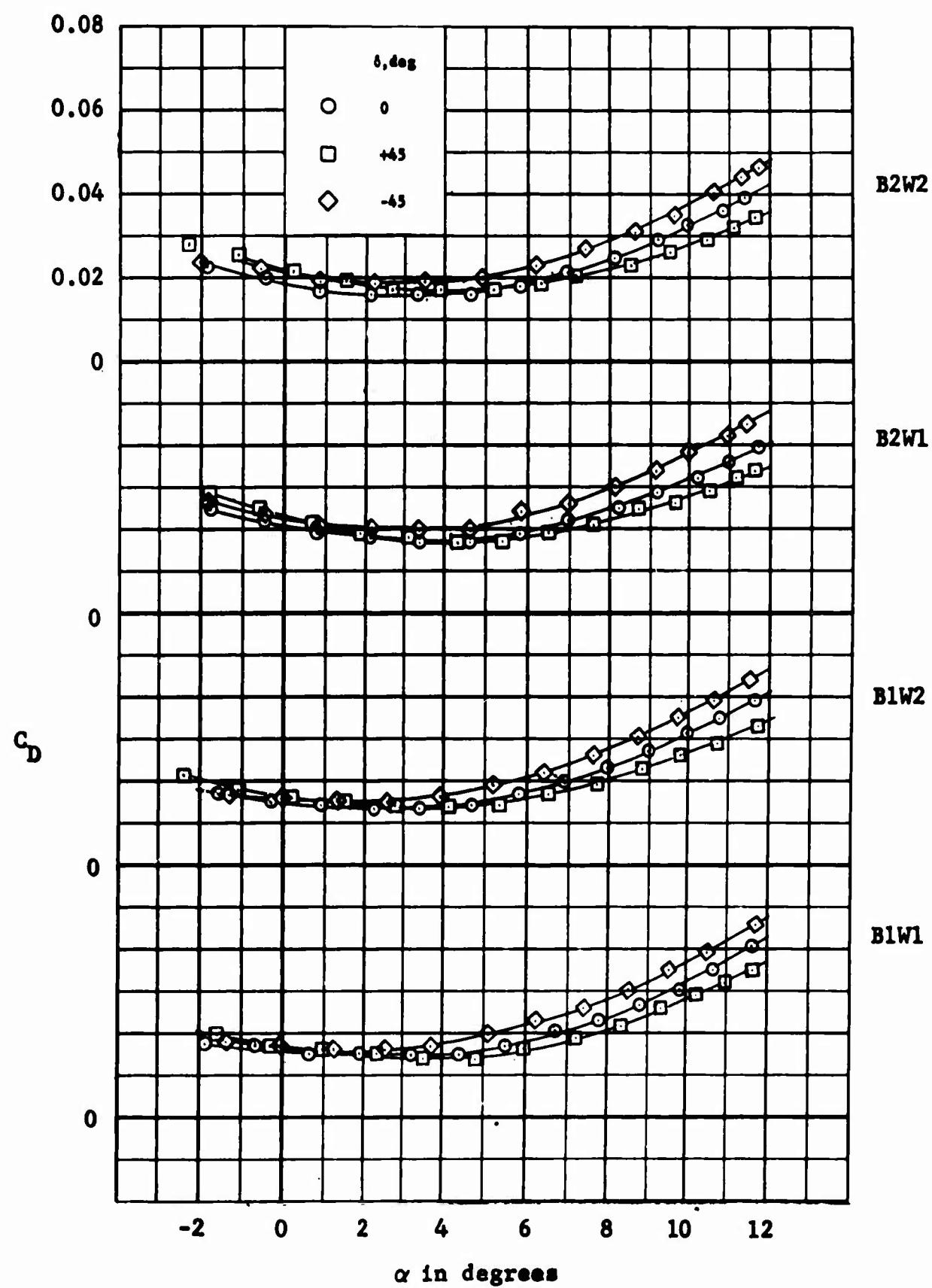


Figure 5 (Concluded)

(b) Low-Wing Configurations

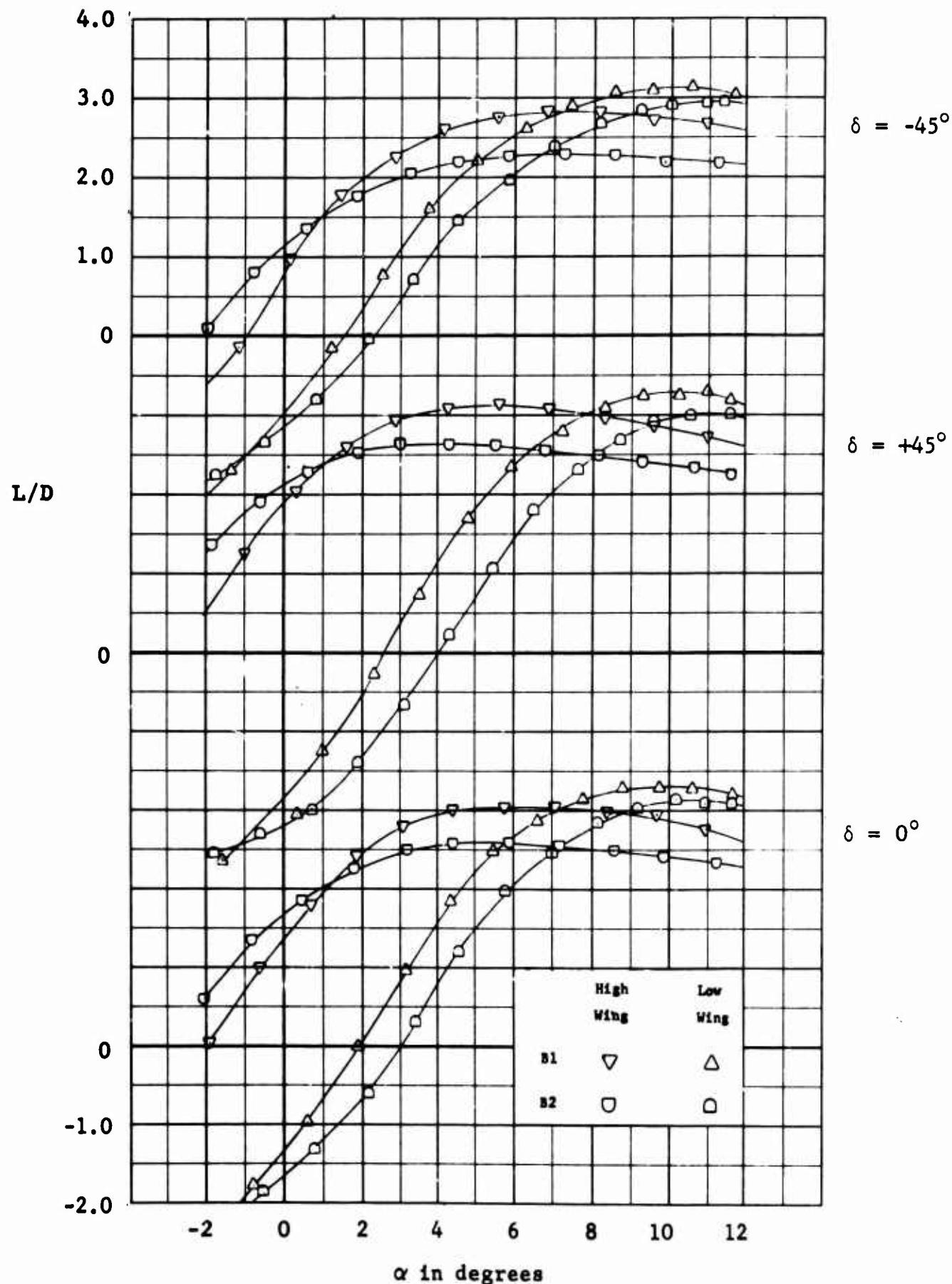


Figure 6 - Effects of Body Volume and Vehicle Orientation on Aerodynamic Efficiency
 (a) Series 1 Wings

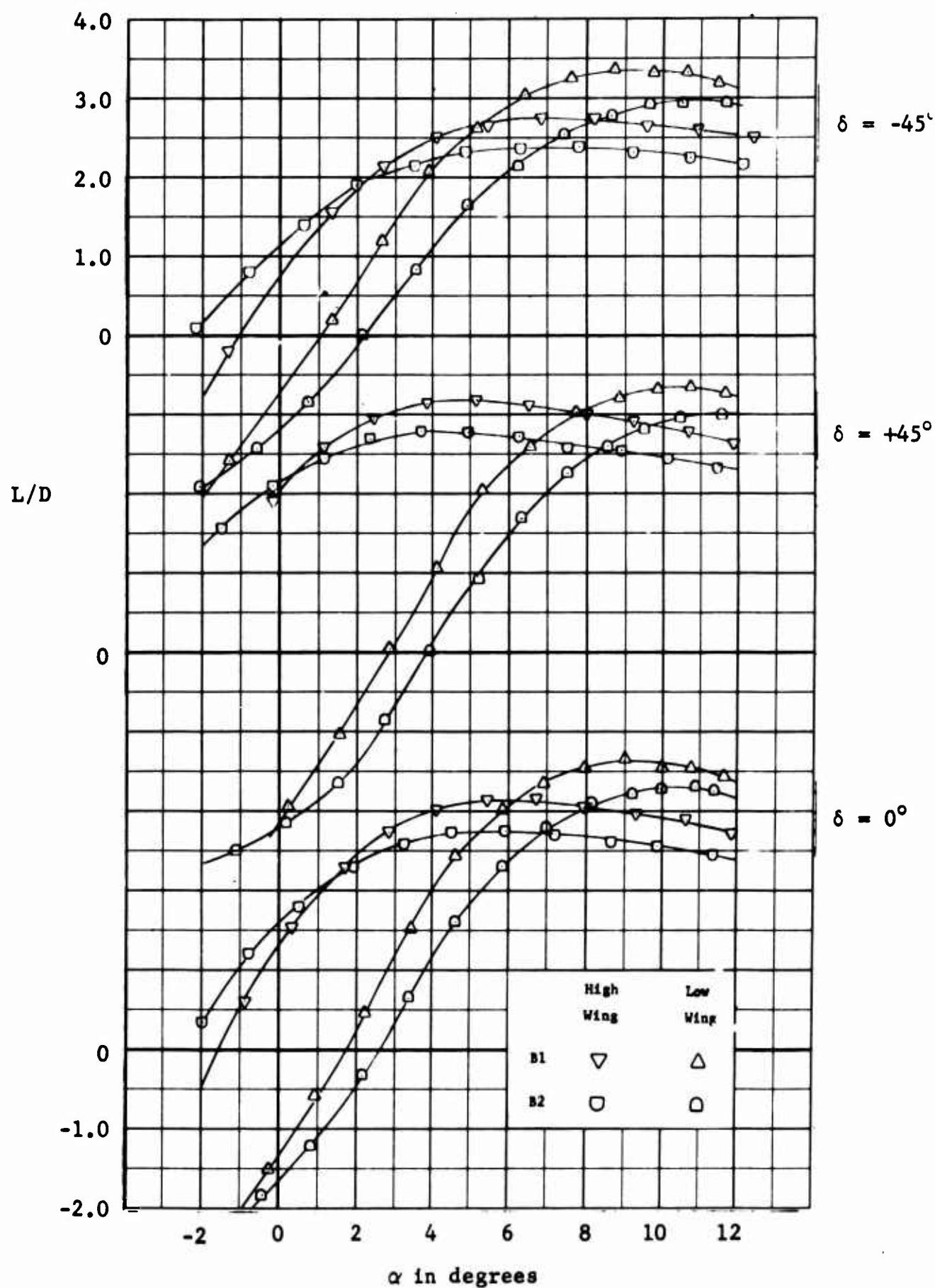


Figure 6 (Concluded)

(b) Series 2 Wings

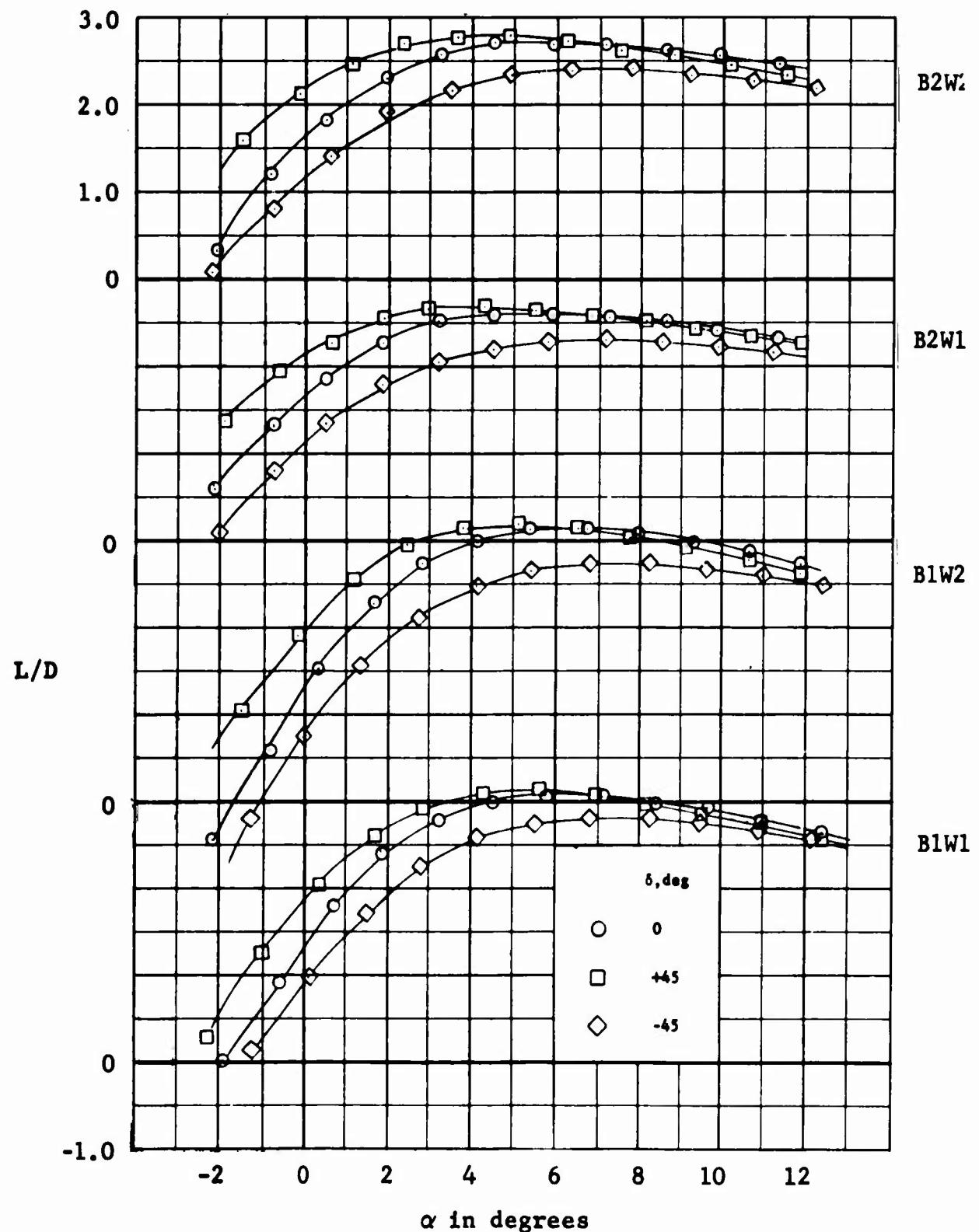


Figure 7 - Effects of Wing-Tip Dihedral on Aerodynamic Efficiency
 (a) High-Wing Configurations

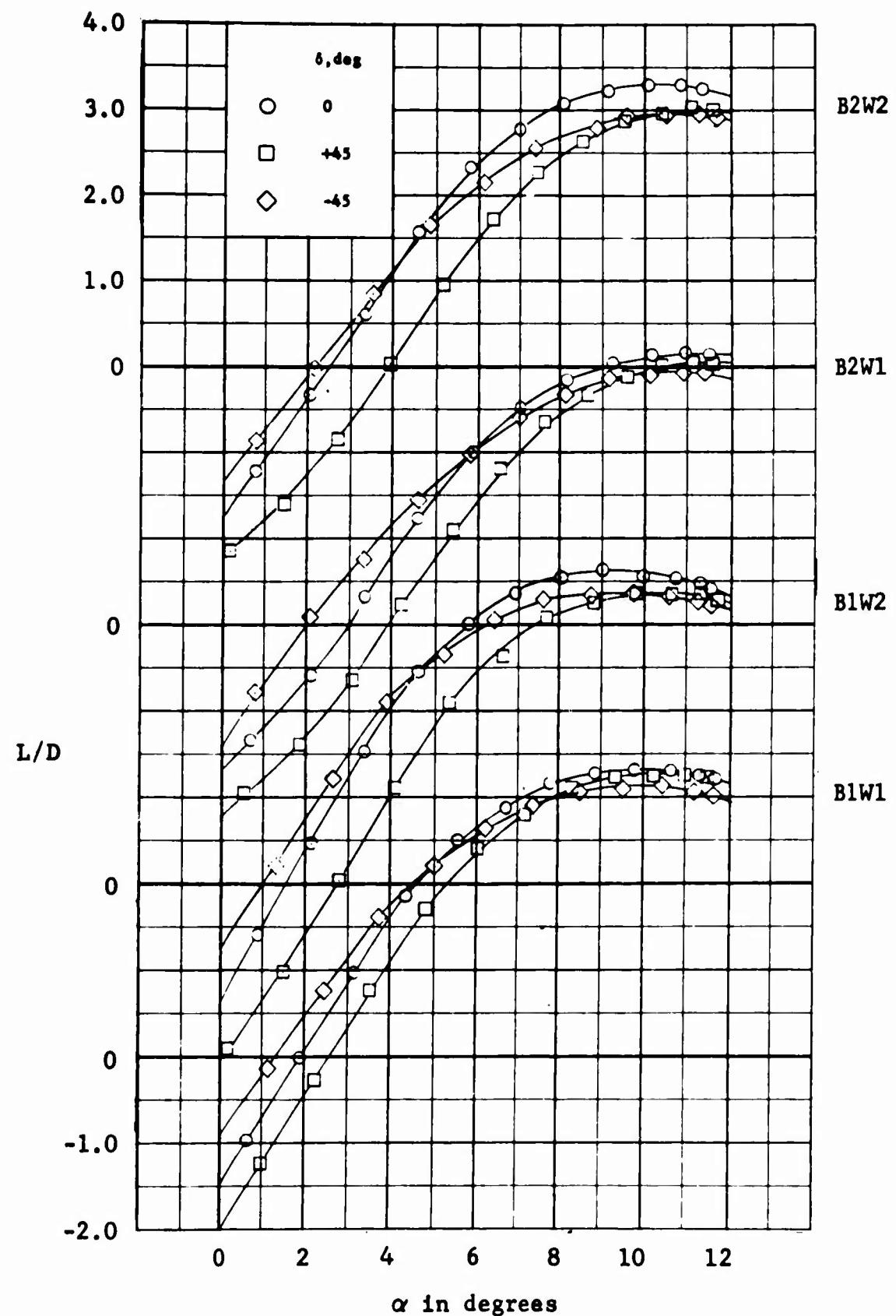


Figure 7 (Concluded)
(b) Low-Wing Configurations

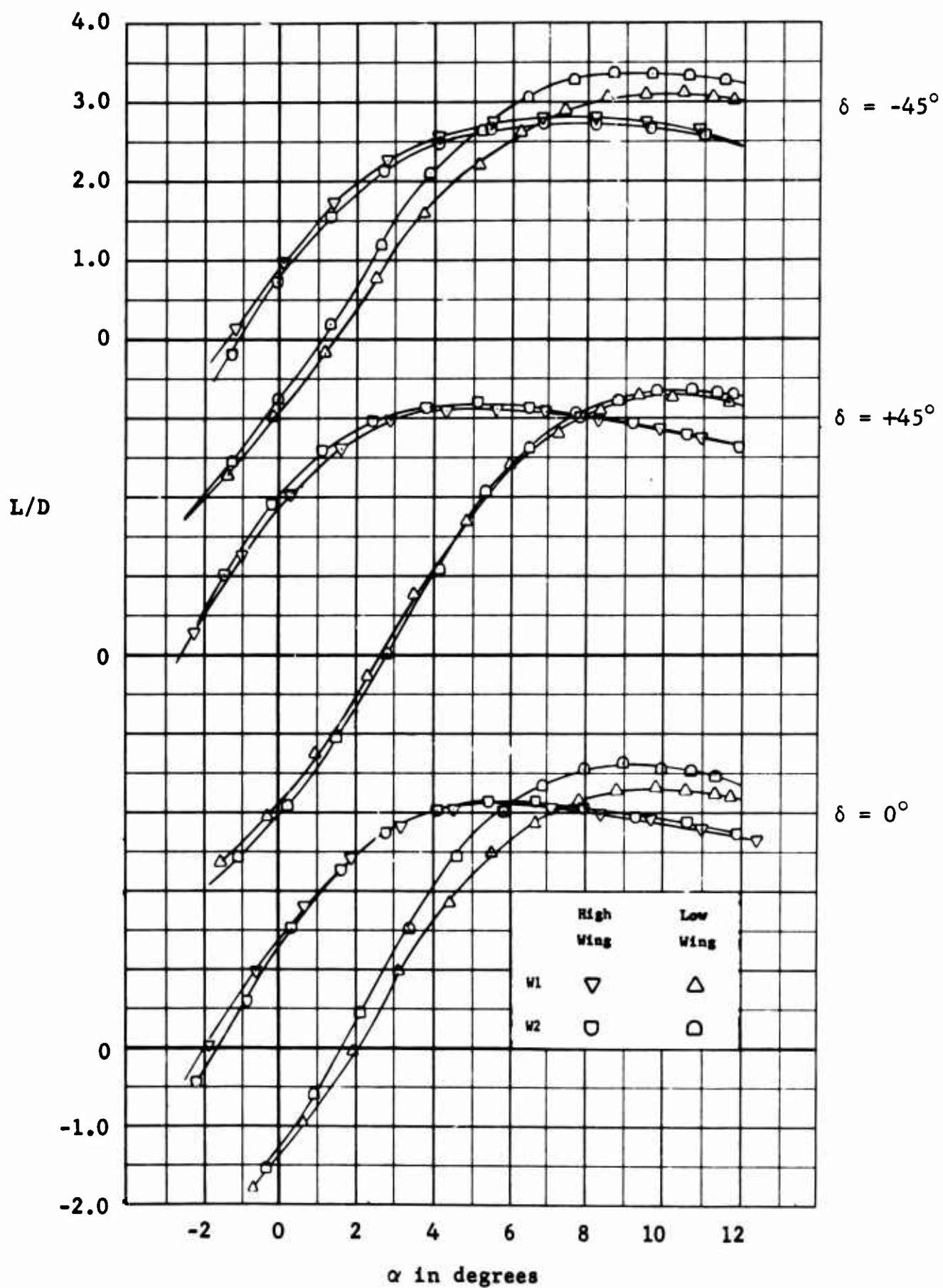


Figure 8 - Effects of Wing-Planform on Aerodynamic Efficiency
(a) B1 Configurations

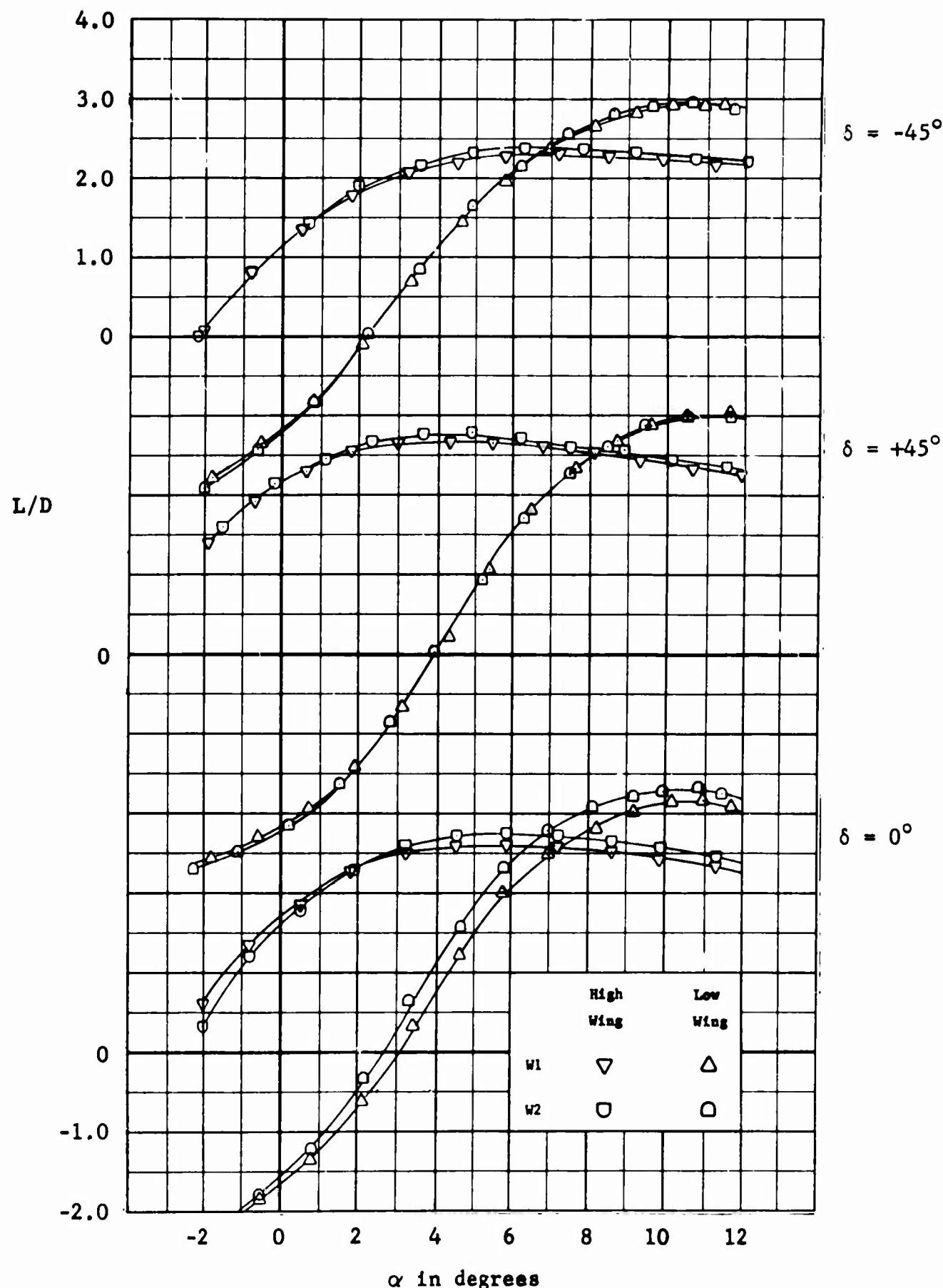


Figure 8 (Concluded)
(b) B2 Configurations

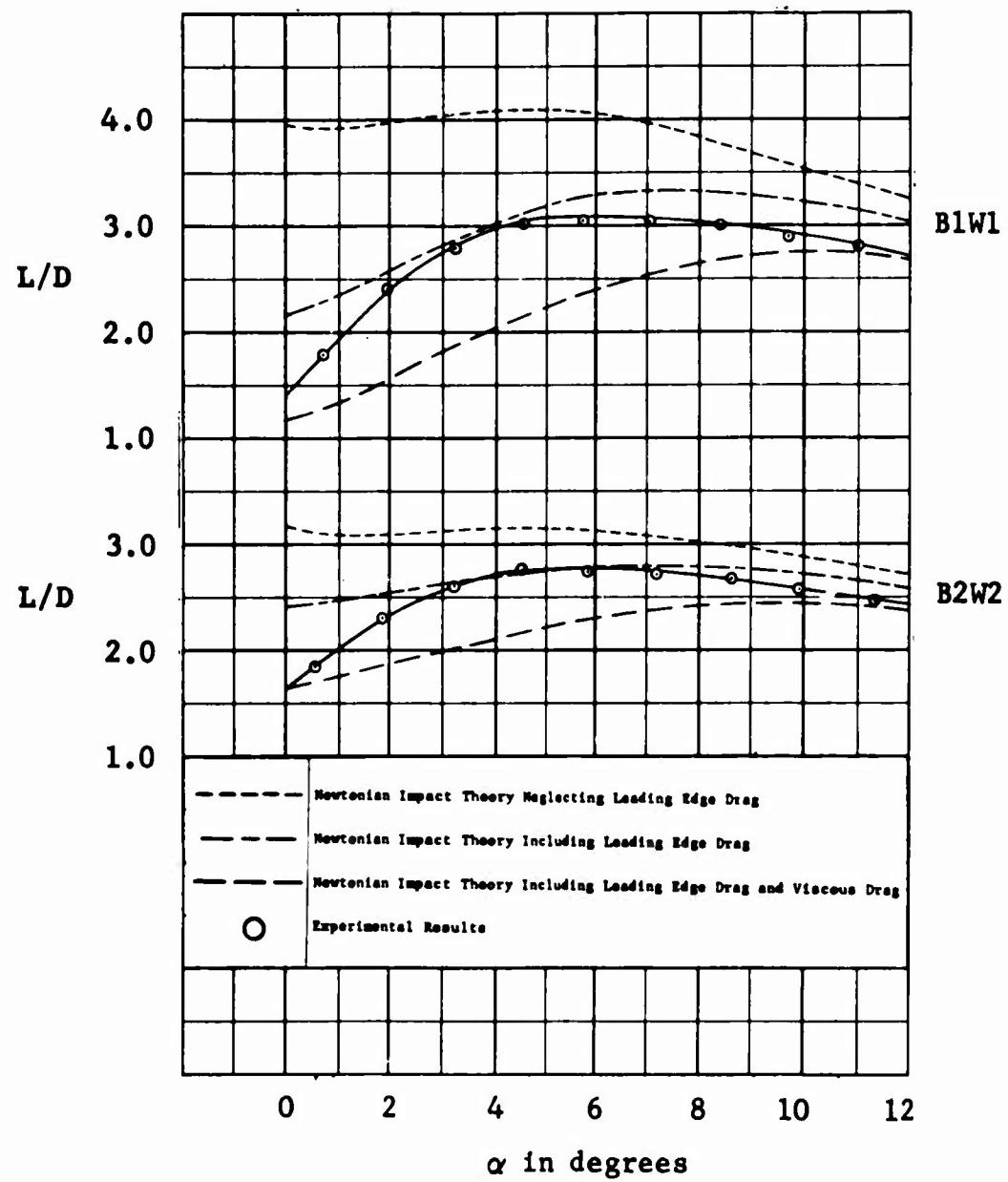


Figure 9 - Experimental and Theoretical Comparison of the Aerodynamic Efficiency of Two Flat-Plate, High-Wing Configurations

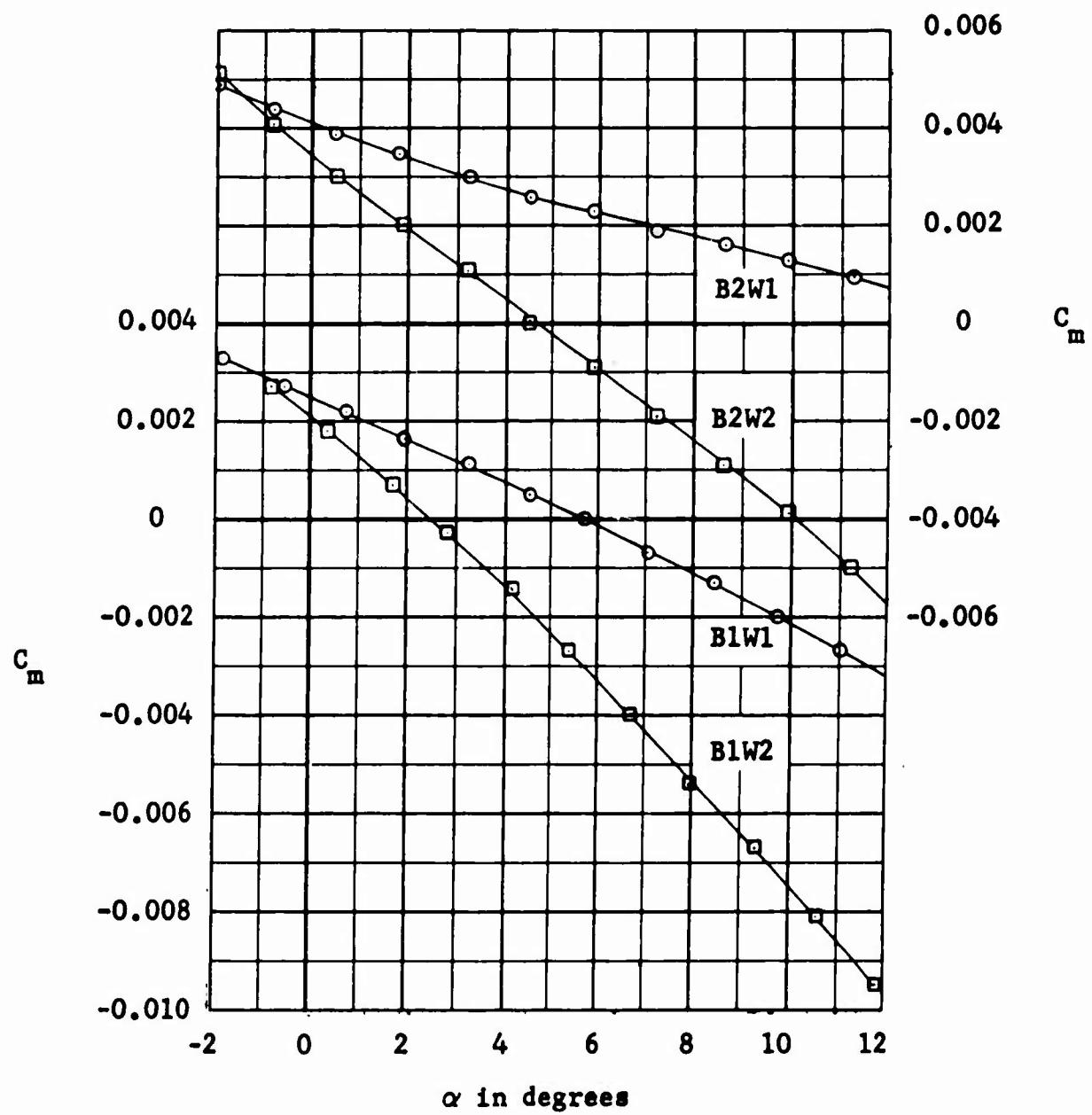


Figure 10 - Effects of Body Volume and Wing Planform on Pitching Moment Coefficient (High-Wing Configurations)
 (a) $\delta = 0^\circ$

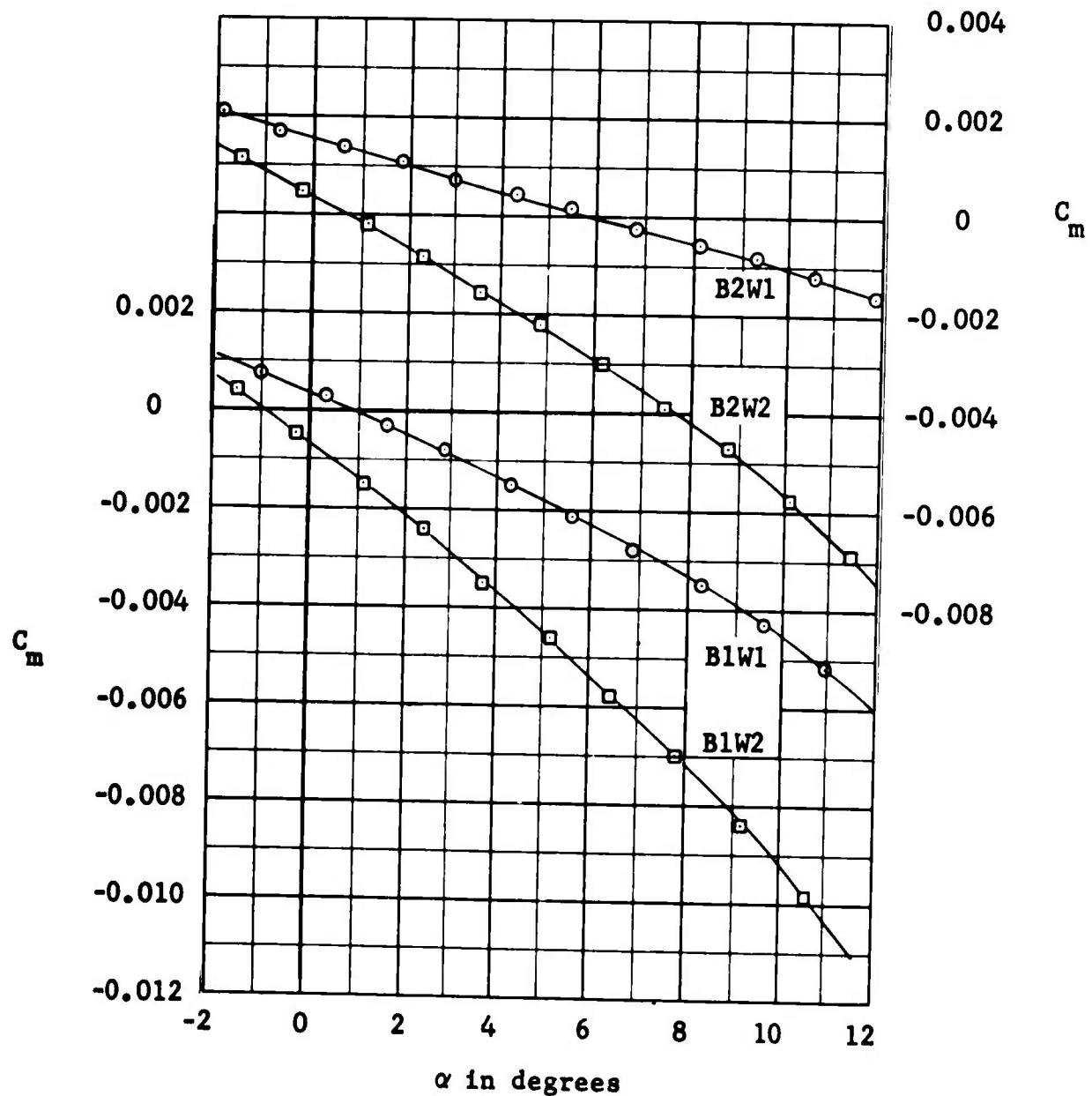


Figure 10 (Continued)

(b) $\delta = 45^\circ$

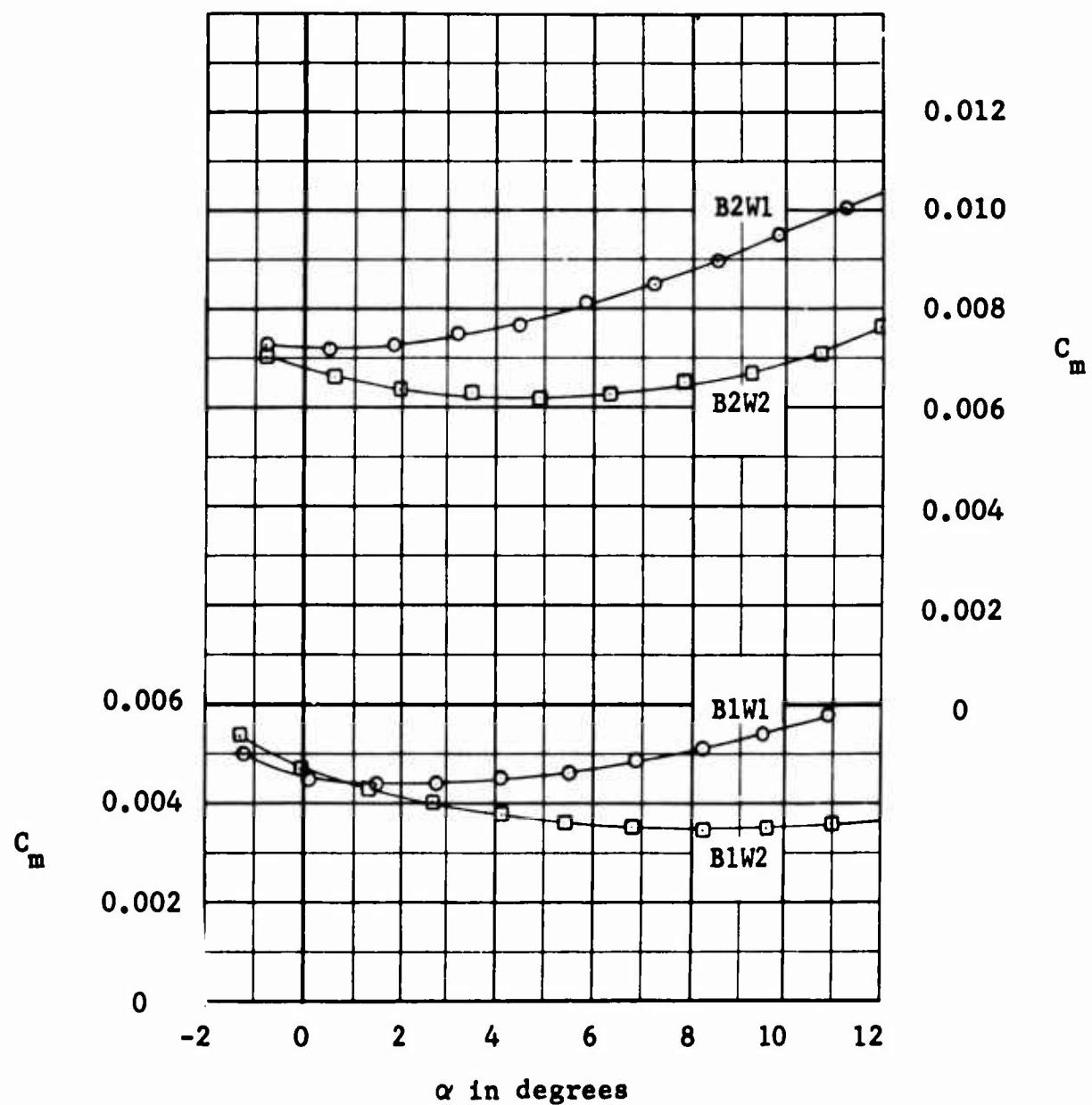


Figure 10 (Concluded)

(c) $\delta = -45^\circ$

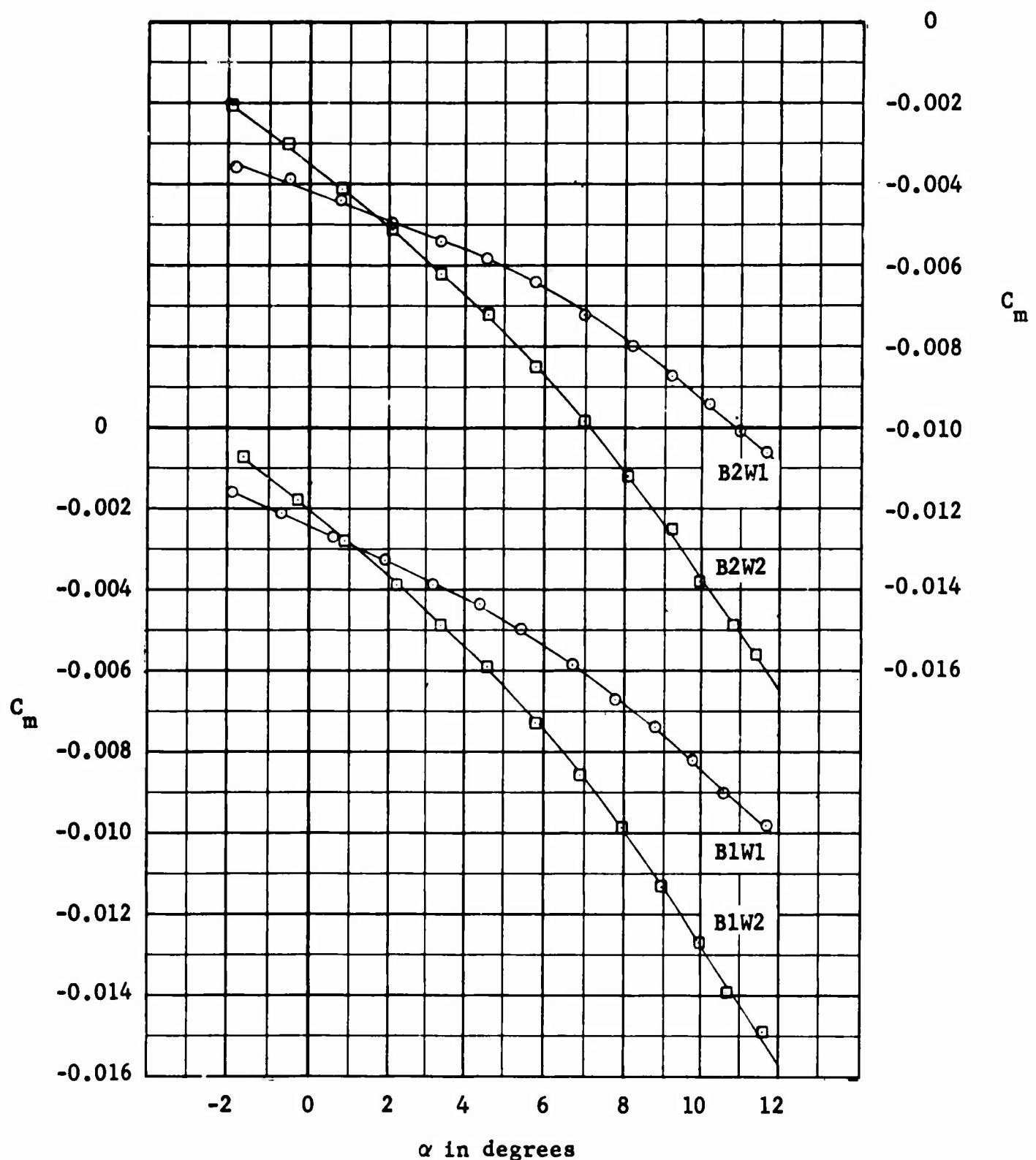


Figure 11 - Effects of Body Volume and Wing Planform on Pitching Moment Coefficient (Low-Wing Configurations)
 (a) $\delta = 0^\circ$

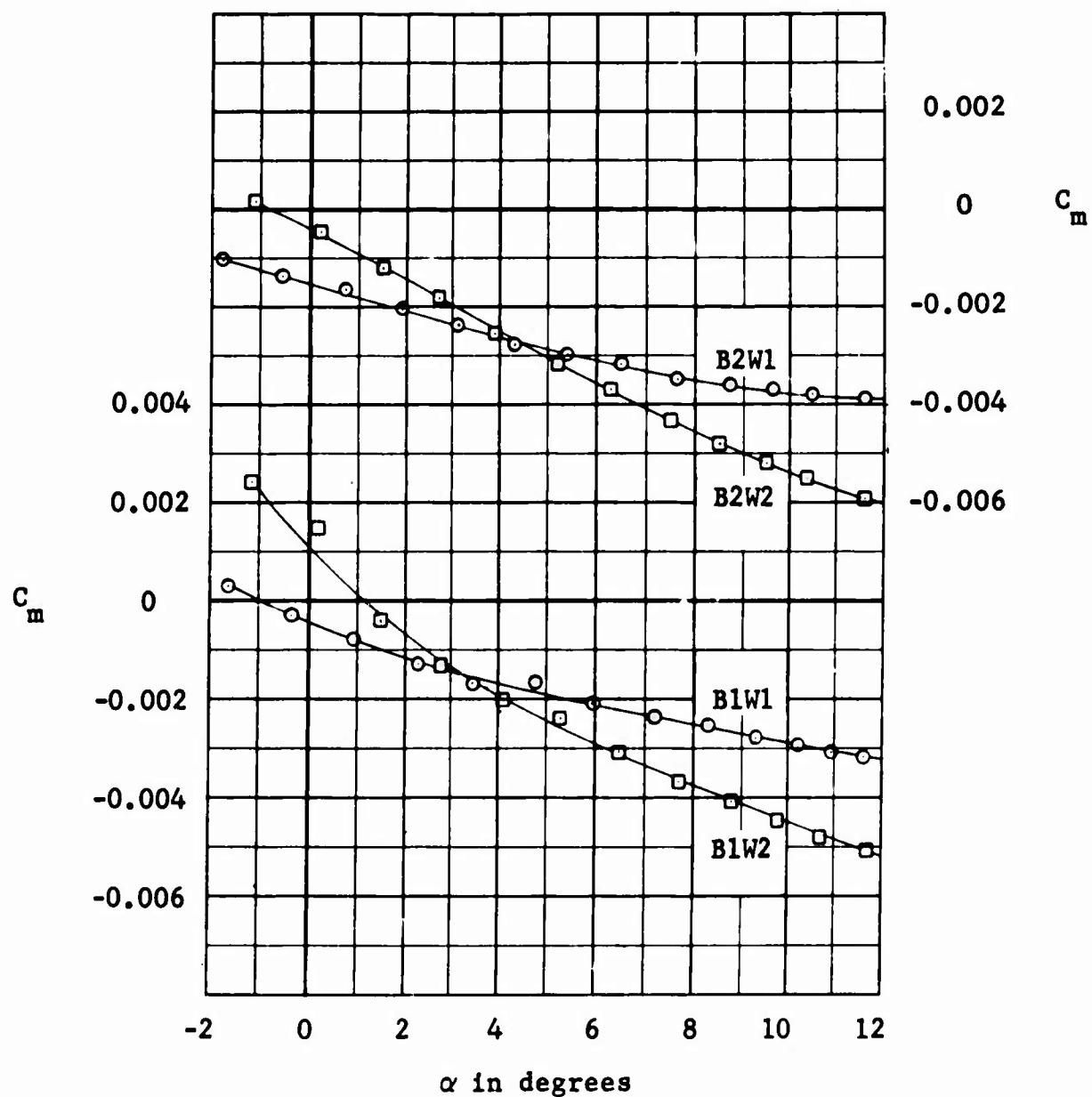


Figure 11 (Continued)

(b) $\delta = 45^\circ$

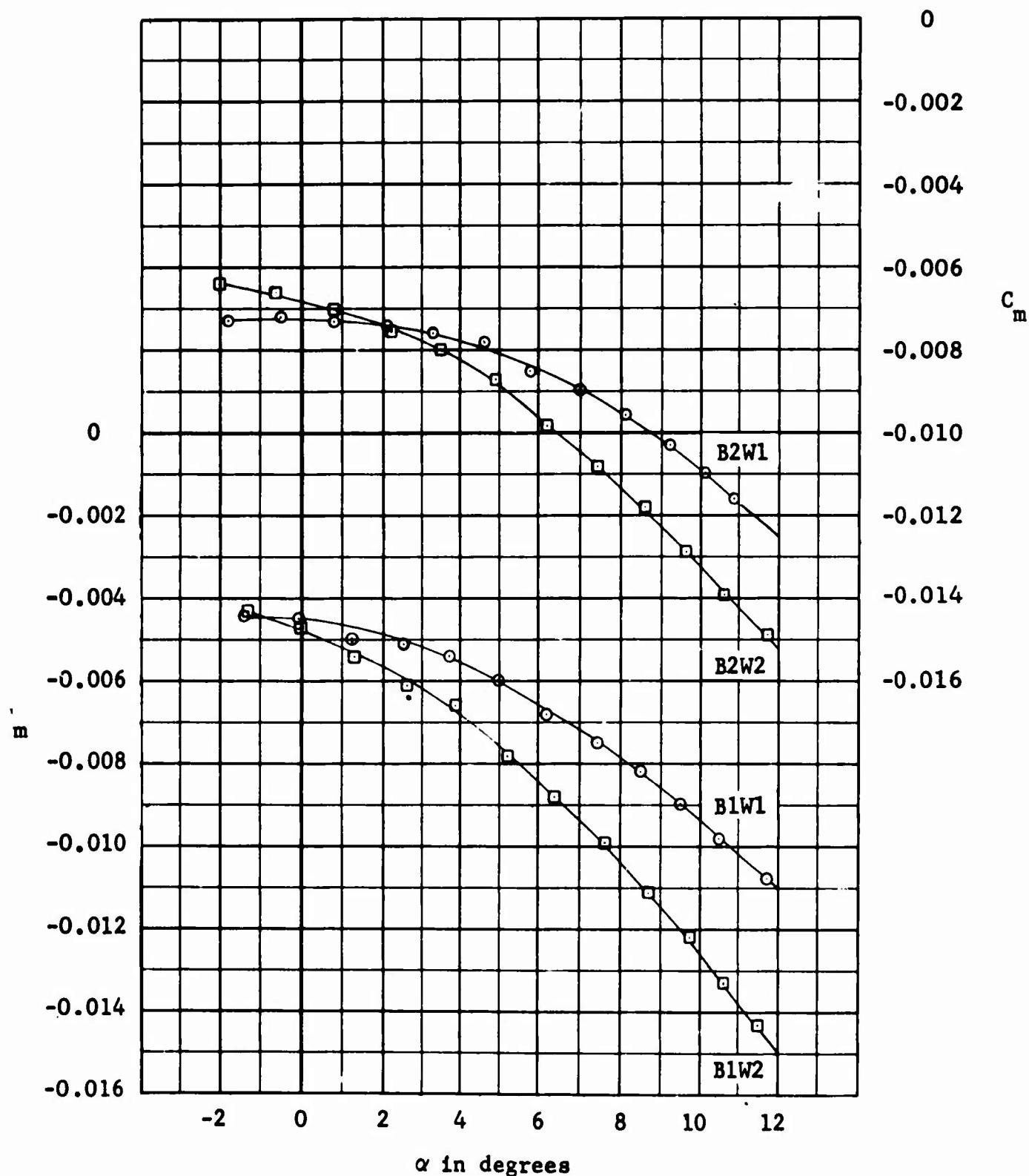


Figure 11 (Concluded)

(c) $\delta = -45^\circ$

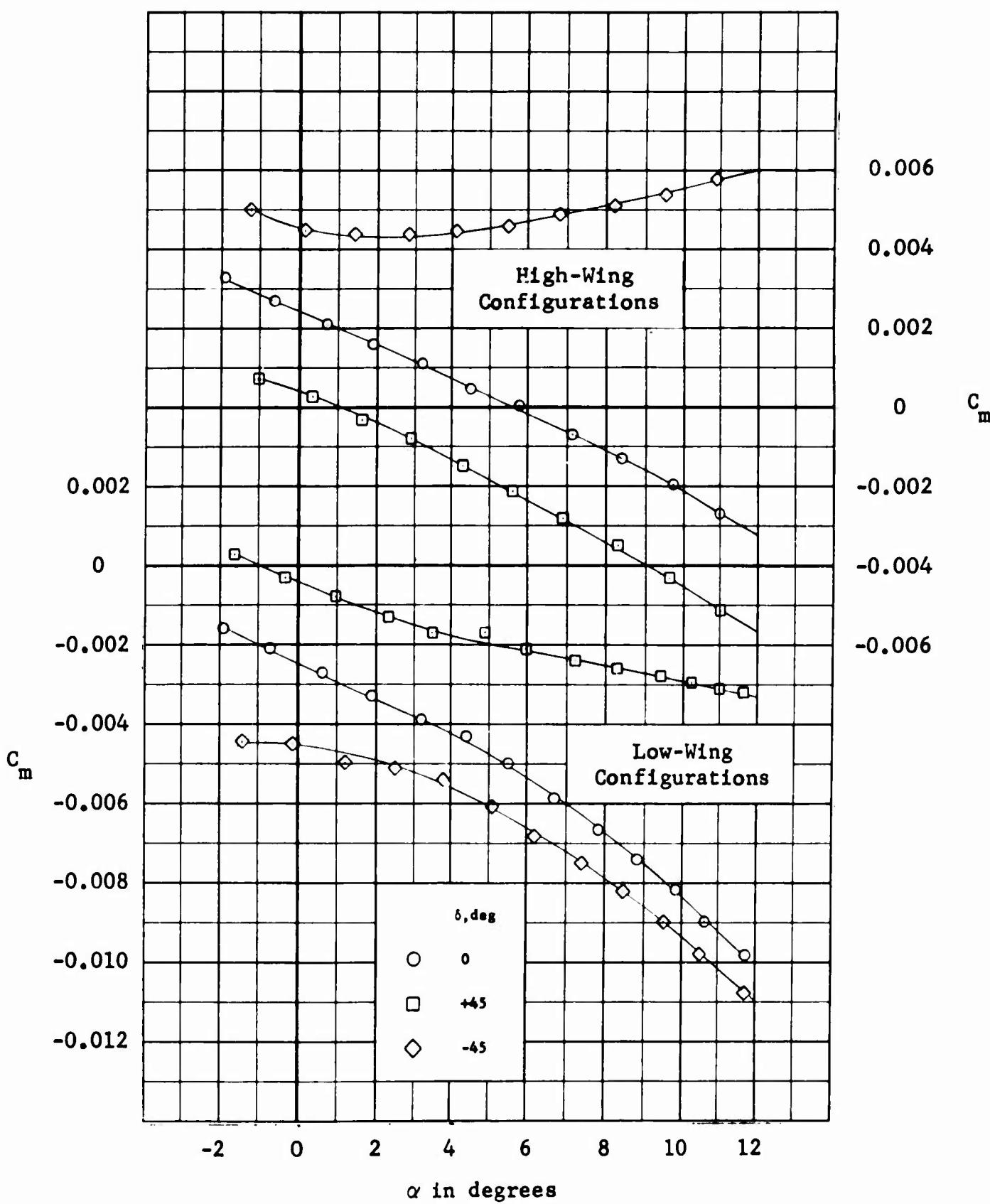


Figure 12 - Effects of Wing-Tip Dihedral and Vehicle Orientation
on Pitching Moment Coefficient
(a) B1W1 Configurations

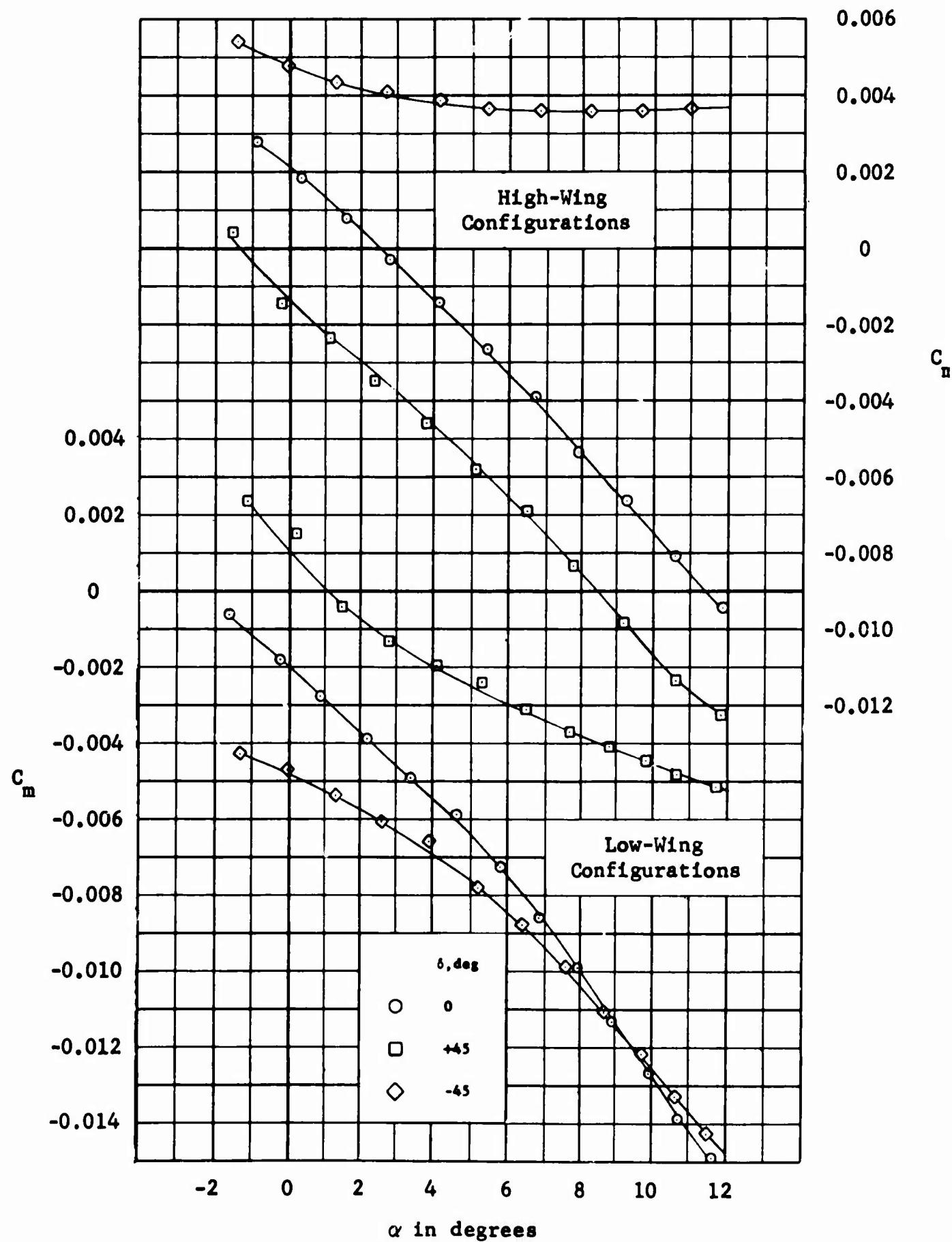


Figure 12 (Continued)
(b) BLW2 Configurations

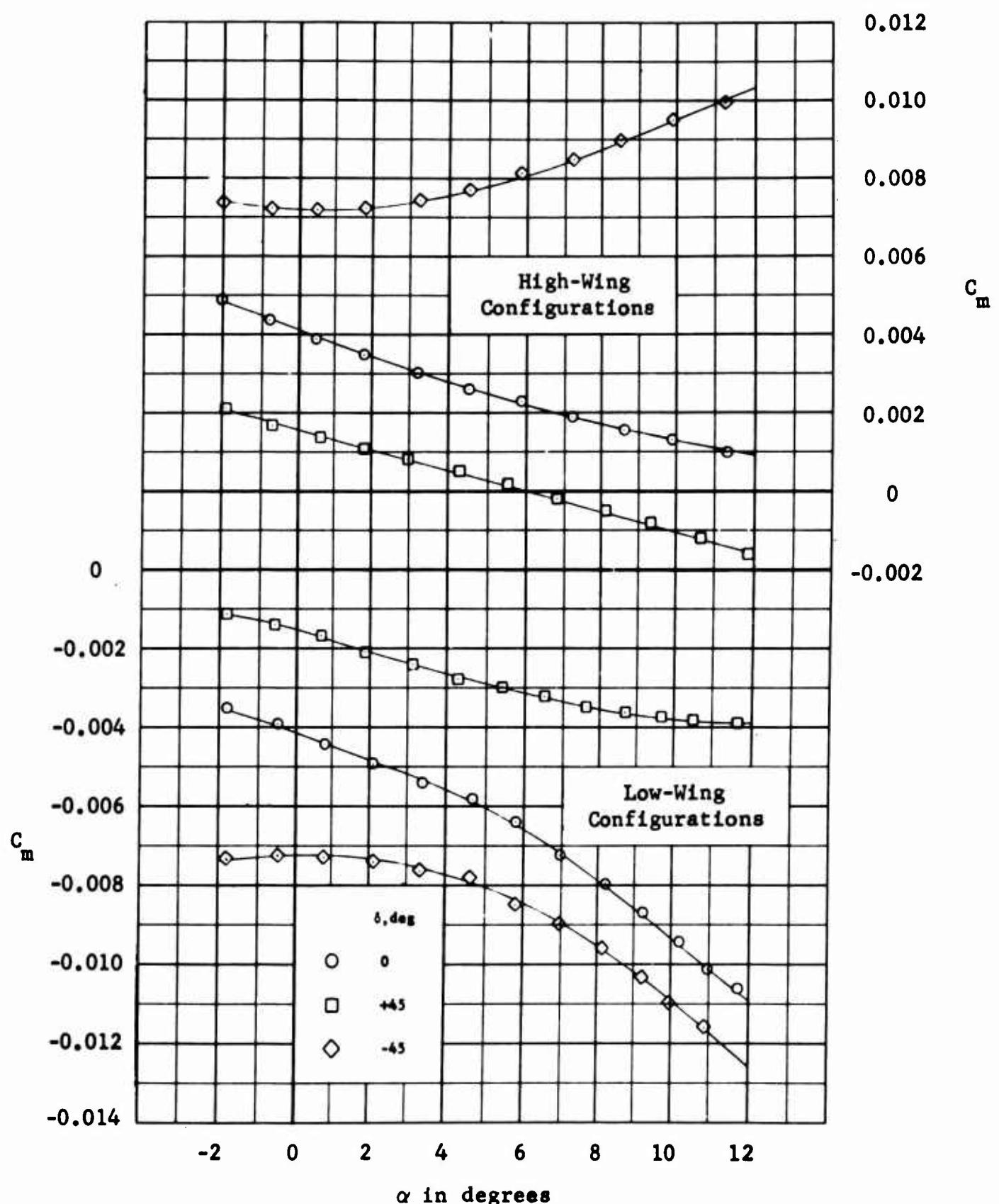


Figure 12 (Continued)
(c) B2W1 Configurations

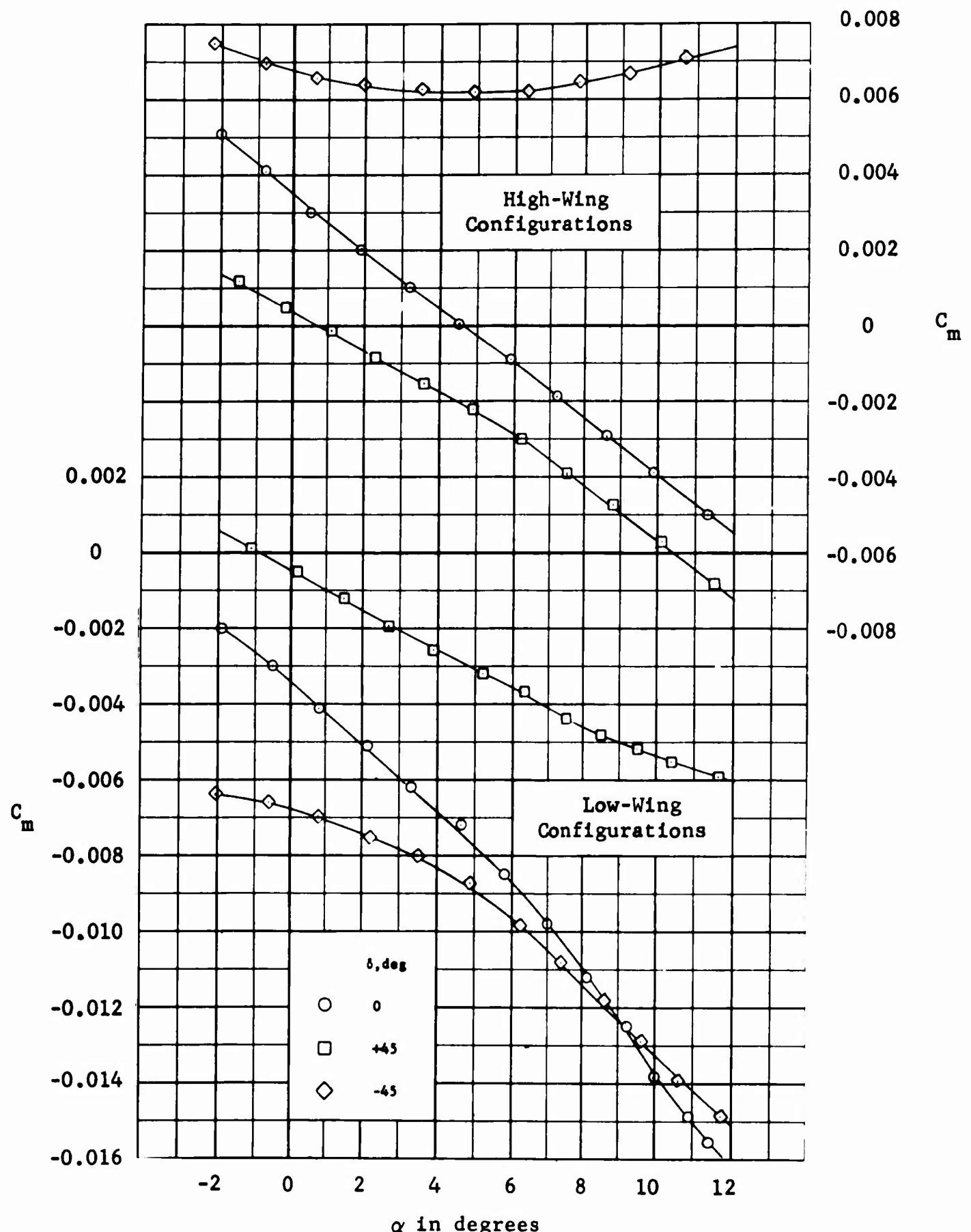


Figure 12 (Concluded)
(d) B2W2 Configurations

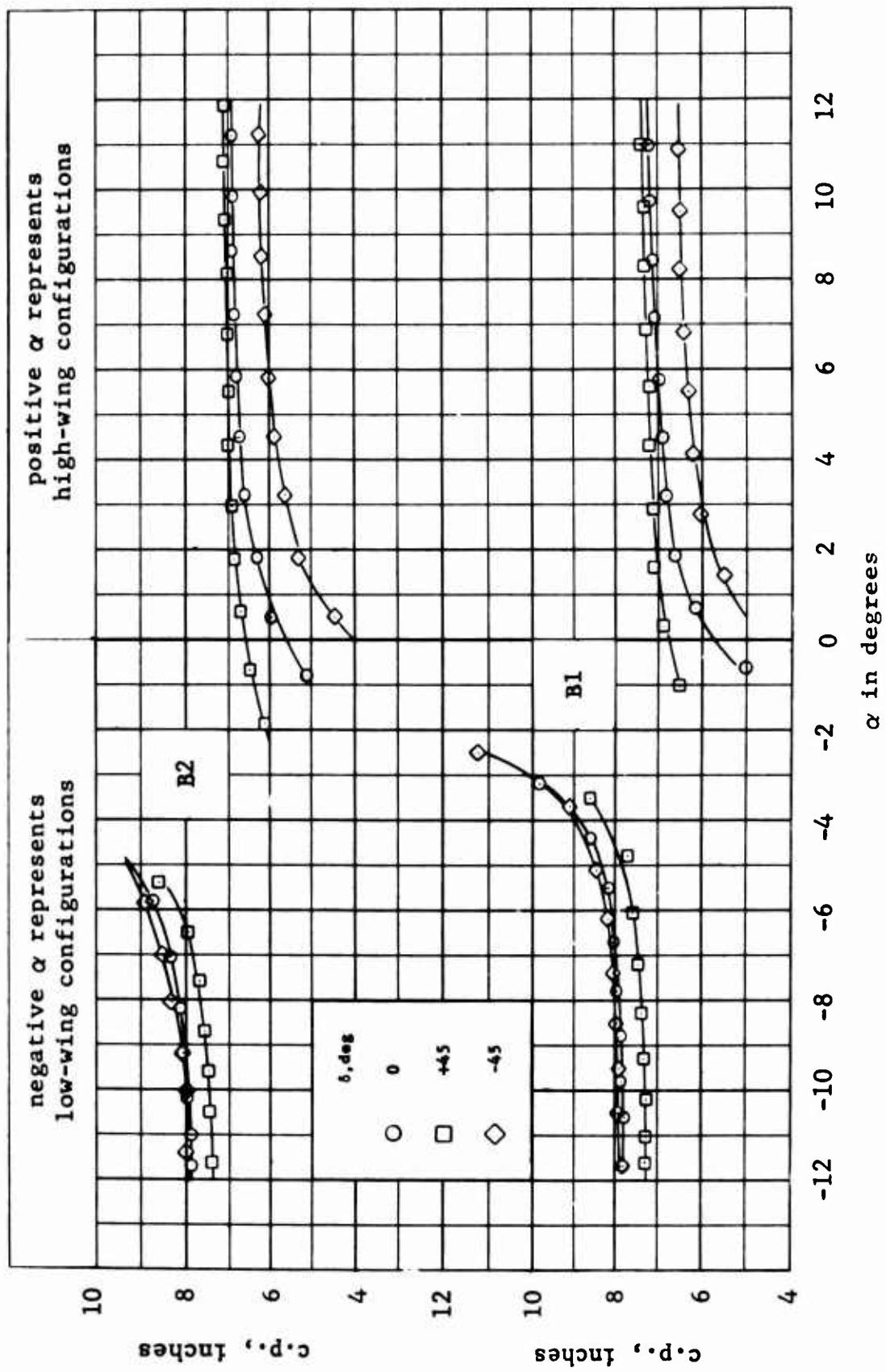


Figure 13 - Variation of Center of Pressure
With Angle of Attack
(a) Series 1 Wings

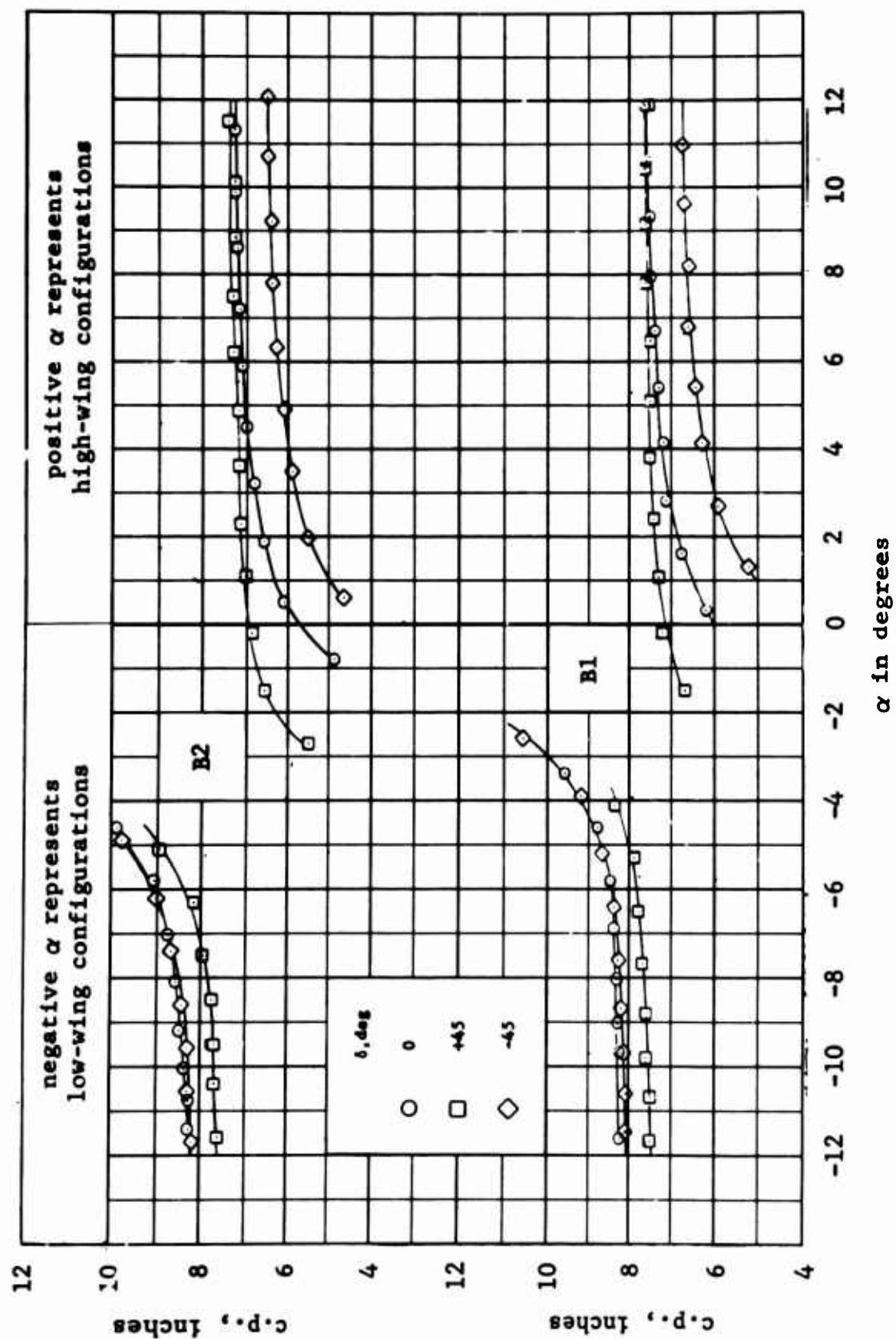


Figure 13 (Concluded)
(b) Series 2 Wings

Unclassified

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	2b GROUP

3 REPORT TITLE

LONGITUDINAL AERODYNAMIC CHARACTERISTICS OF SEVERAL HYPERSONIC AIRCRAFT CONFIGURATIONS AT A MACH NUMBER OF 6.26

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Krouse, John R. and Ellis, Bertram K.

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13. ABSTRACT

Wind-tunnel tests were conducted at a Mach number of 6.26 to determine the longitudinal aerodynamic characteristics of several conceptual hypersonic aircraft configurations, consisting of various half-cone-cylinder bodies and double-delta wings. Effects of body volume, vehicle orientation, wing planform, and wing-tip dihedral were determined. In general, the lift-to-drag ratios of all high-wing configurations varied slightly over an angle-of-attack range of 0° to 12°, reaching maximum values of roughly 3.2 near 6°. On the other hand, the lift-to-drag ratios of all low-wing configurations increased continuously with increasing angle of attack, eventually reaching maximum values of roughly 3.6 near 10°. In all cases, fuselage base drag accounted for less than 10 percent of the total drag. For the arbitrarily chosen center-of-gravity location, all low-wing configurations were stable but unbalanced; whereas several high-wing configurations were both stable and balanced.

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<p>Hypersonic Aircraft</p> <p>Aerodynamic Forces</p> <p>Aerodynamic Efficiency</p> <p>Longitudinal Stability</p> <p>Static Stability</p>						
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